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ULTRASOUND*

Ultrasound in gynecology

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Abstract This paper reviews the various examination thechniques, the clinical indications, and the imaging findings for US studies of the female pelvis in patients with gynecological problems. Ultrasound, in fact, is the preferred imaging modality in the study of the female pelvis, and provides information of basic importance in detecting and characterizing pelvic masses of uterine, ovarian, or adnexal origin, providing also criteria useful in predicting their benign vs malignant nature. In patients with abnormal bleeding, transvaginal US helps in determining the presence of morphological and structural changes of the endometrium and, with the use of sonohysterography, provides excellent delineation of the endometrial cavity, guiding appropriate planning of therapeutic procedures. Ultrasound plays a very important role in the evaluation of patients with acute pelvic pain. It allows identification of ovarian torsion and has both diagnostic and therapeutic capabilities in patients with pelvic inflammatory disease through guidance of abscess drainage via the transvaginal route. In suspected ectopic pregnancy, US, together with quantitative measurements of hCG levels, can be considered the best imaging procedure to guide to the diagnosis. Ultrasound has an important role also in the study of female infertility. In this field it can be used to identify and document the integrity of the reproductive tract as a conduit for the passage of gametes and embryos, to detect pathological changes that may be causes or contributing factors of female infertility, to monitor cyclic changes of pelvic organs to document normal physiology or pathological situations, and to guide infertility treatment.

Keywords Ultrasonography · Transvaginal ultrasonography · Gynecology · Pelvic masses · Abnormal bleeding · Acute pelvic pain · Female infertility

Introduction

Sonography is commonly regarded as the preferred imaging modality in the study of the female pelvis. It is widely available, noninvasive, relatively cheap, does not use ionizing radiations, and is able to provide definitive diagnostic information in a large variety of clinical settings. Furthermore, when additional modalities are needed for proper disease evaluation, it allows choice of the most appropriate pathway to reach the diagnosis.

The scope of this paper is to review the various examination techniques, the clinical indications, and the imaging findings for US studies in patients with gynecological problems.

Examination techniques

A variety of examination techniques can be used for the US study of the pelvis. Transabdominal sonography us-

ing curved-array transducers can still be considered the first approach to the patient, since it provides global delineation of all pelvic organs and analysis of relationships of any structure with uterus and ovaries. In many cases this technique may be sufficient, and transvaginal examination is not necessary. Furthermore, in patients with large lesions, only the panoramic capabilities provided by transabdominal US allow complete evaluation of the disease process [1]. Transvaginal sonography is the best examination technique for evaluating the female pelvis. When the probe is positioned in the vaginal fornices, in fact, the pelvic structures are within the focal zone of the ultrasound beam, and high-frequency, high-resolution transducers can be employed; thus, the morphology and structure of ovaries and uterus can be analyzed with higher accuracy than with conventional transbdominal technique, and smaller structures, both normal and abnormal, can be imaged. Furthermore, higher sensitivity to flow allows easier detection and evaluation of vascular structures with both color Doppler and spectral analysis techniques. Better diagnostic results can be obtained by this technique over the conventional transabdominal approach in most cases [2, 3]; however, particularly when the patient has not been studied previously, the use of both scanning techniques is commonly suggested. Additional approaches, using transrectal probes or conventional transducers placed over the perineal region, can also be used for selected indications.

A special technique called sonohysterography has been developed to obtain better analysis of the endometrial surface. After accurate cleansing of the cervix, a soft catheter is advanced into the cervical canal and up to 30 ml of sterile saline are injected. Distension of the endometrial lumen is observed with continuous transvaginal sonography, and any irregularity of the surface is well delineated by the hypoechoic contrast medium. The procedure is best performed in the follicular phase. Contraindications include hematometra, pelvic inflammatory disease, or atrophic and stenotic vagina [4, 5, 6].

Sonography can be used also to evaluate tubal patency. For this purpose, injection of an echogenic US contrast medium is needed to delineate the tubes, and a balloon catheter is requested to avoid reflux of contrast through the cervical os. Both passage of the microbubbles through the tubes and spillage into the peritoneal cavity can be assessed with color Doppler or, more recently, with the use of non-linear scanning techniques which allow almost complete cancellation of static tissues, good visualization of the flowing contrast, and better delineation of tubal morphology [5].

It must be remembered that sonography is not only used to evaluate the morphology of pelvic organs. It also has monitoring capabilities. Monitoring differs from diagnostic imaging in that is not limited to assessing the presence of a disease state. It also provides information regarding changes in the appearance of different organ systems in response to normal physiological changes or specific therapies. At the level of the female pelvis, US can detect changes of the uterus and ovary during the menstrual cycle. Correlation of morphological appearances of these organs over time, as well as of cyclic flow changes, with clinical and laboratory parameters, allows further insight into normal or pathological function of the female reproductive system.

Pelvic masses

Patients in whom the clinical findings are mainly characterized by presence of an asymptomatic or poorly symptomatic mass in the pelvis may have a large variety of pathological conditions, and US is commonly the initial and often the only imaging procedure performed in them. It must be stressed that, when confronted with a pelvic space-occupying lesion, the clinician has to consider a variety of clinical parameters which are crucial to determine the possible nature of the disease process, as well as the subsequent diagnostic work-up of the lesion. Among them, patient's age and size and consistency of the mass are the most significant [7]. For instance, premenopausal patients, in whom most lesions are of functional origin, who present with an adnexal mass of 5–6 cm of cystic consistency, are usually followed-up on clinical grounds; US imaging is requested only for lesions which do not disappear at further controls, whereas laboratory tests are usually performed after US has clarified the characteristics of the mass. On the contrary, in postmenopausal patients, in whom ovarian tumors are more frequent, US is commonly performed immediately after physical examination [7, 8] in order to provide the physician with information on the possible nature of the disease process.

Enlarged uterus

Although uterine enlargement as the cause of a pelvic mass can be easily recognized at physical examination, US is commonly requested to further characterize structural changes of the uterus and to measure it. Fibroids (or, more correctly, fibroleiomyomas), are the most common tumor of the uterus (they affect 40 % of women over 35 years), and the most common cause of uterine enlargement. They are benign tumors made of smooth muscle fibers intermixed with a variable amount of fibrous connective tissue. They have a smooth outer margin, with a fibrous pseudocapsule dividing them from the myometrium. As they enlarge, they tend to present areas of central necrosis and cystic degeneration due to overgrowth of blood supply. Fibromas are usually

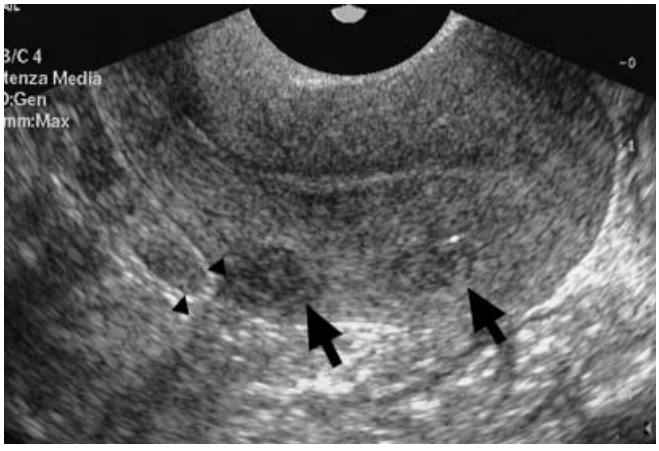


Fig. 1 Transvaginal US showing two small intramural uterine leiomyomas *(arrows)*. The largest lesion causes a small bulge on the uterine surface and lateral acoustic shadowing *(arrowheads)*

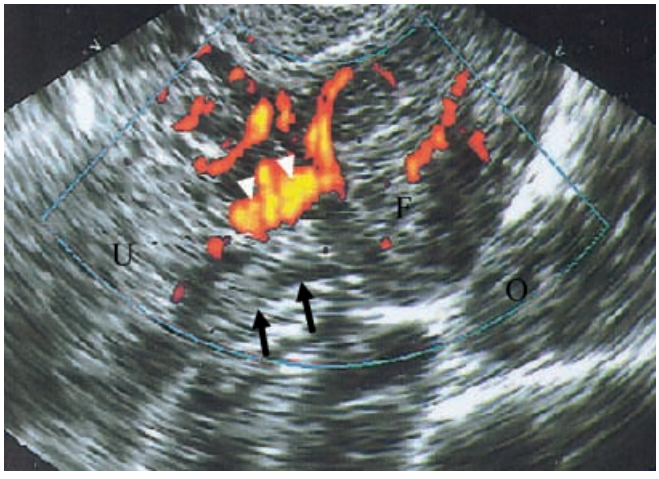


Fig. 2 Transvaginal US of pedunculated fibroma. The use of the power Doppler technique allows identification of vessels *(arrowheads)* within the pedicle *(arrows)* running from the uterus *(U)* to the fibroma *(F)*. *O* ovary

multiple; they grow under estrogen influence during the reproductive years, and usually decrease in size after menopause. They are most commonly located in the intramural myometrium. Submucosal fibromas can cause abnormal uterine bleeding from vascular engorgement and/or erosion of the overlying endometrium. Subserosal fibromas may project from the uterine surface and simulate an adnexal mass; pedunculated fibromas may lie at some distance of the uterus and they nature may be difficult to diagnose [9]. On US studies uterine fibroids usually appear as solid, discrete, well-defined masses with a thin hypoechoic periphery. They may be hyper-, iso-, or hypoechogenic related to the myometrium (Fig. 1) [10]. Shadowing at their lateral borders is common and may be the only clue to US detection of iso-echoic masses. They may contain internal cystic areas and may be calcified. Calcifications are usually large and can have a curvilinear or irregular, patchy morphology. Fibromas have usually relatively poor blood flow, and color Doppler signals are mostly seen at their periphery. Although US is currently regarded as the most cost-effective modality for fibroids detection, diagnostic difficulties may occur. Small, intramyometrial, isoechogenic masses are difficult to recognize, and can be detected only if they cause distortion of the outer profile of the uterus or of the endometrial cavity. Subserosal and pedunculated fibroids can be misinterpreted as adnexal masses. Careful analysis of their relationships, as well as of their movements during transvaginal US under pelvic palpation, can help in differentiating them from adnexal masses (subserosal fibroids move together with the uterus during palpation). In pedunculated fibroids, the use of color Doppler can help to identify the pedicle of the lesions through detection of its vessels, thus allowing the diagnosis (Fig. 2) [9, 10]. Treatment of fibroids is decided based on symptomatology; US can be used to follow-up volume decrease of treated lesions after therapy.

Uterine leiomyosarcomas are the malignant counterpart of uterine fibromas. They are rare and usually occur in the elderly. At US they appear as bulky uterine masses that are indistinguishable from large non-malignant fibromas; however, the clinician can be alerted to the diagnosis by their rapid progression over time [9].

Simple cysts

Simple cysts are probably the most common asymptomatic pelvic mass. In premenopausal women, simple adnexal cysts are usually of functional origin, usually due to failure of involution of the follicle or the corpus luteum. They present the classic findings of cysts: smooth and regular margins; lack of internal echoes; and increased through transmission. Size of the cyst is the finding on which subsequent management is usually based. Lesions up to 6 cm in premenopausal women, or up to 5 cm in postmenopausal women, can be simply followed-up by US or clinical examination, and usually disappear within a few months [7, 8]. Failure to regress may be an indication for surgery. It must be remembered that up to one-third of pregnancies are associated with a corpus luteum cyst which normally regress by approximately 18–20 weeks of gestation. Large cysts are more difficult to manage, firstly because the likelihood of spontaneous regression decreases with increasing size of the cyst, and secondly because, although simple cysts can reach even 8–10 cm in size, lesions larger than 6 cm have higher probability of being a benign neoplasm, rather than a functional cyst.

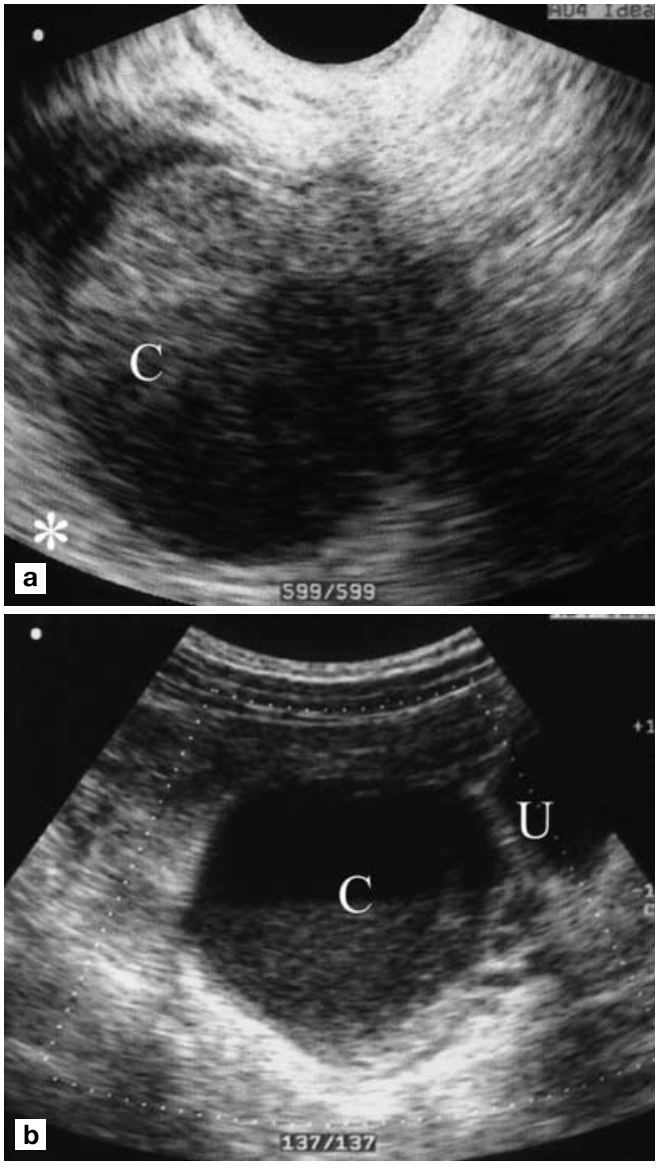


Fig. 3 a, b Ultrasound of hemorrhagic cyst. **a** Transvaginal US demonstrates a solid-appearing mass *(C)*, but with some posterior acoustic enhancement *(asterisk)*. **b** Transabdominal US obtained 8 days later. The structural pattern is changed, and a fluid–fluid level is well visualized. *C* cyst; *U* urinary bladder

Hemorrhagic cysts

Hemorrhage within a cyst makes the diagnosis more difficult. Presence of clot, lysis, and retraction make the US pattern quite variable. Internal echoes, septa, mural nodules, solid components, and fluid-debris levels are seen; septa may even be relatively thick, as well as the cyst wall. Ruptured cysts may be associated with fluid in the Douglas pouch. Also, some lesions may present with a solid-like appearance, with an internal pattern made of many small echoes of medium-to-high reflectivity. Increased through transmission, however, is usually present. The parameter which has been proven most important for the diagnosis of these conditions is changes over time of the internal structure (Fig. 3). Although hemorrhagic cysts can present with a structural pattern similar to ovarian neoplasms, identification of changes over time suggests the correct diagnosis, thus indicating the need for further follow-up before deciding for surgery [7, 8, 12].

Ovarian neoplasms

The prevalence of ovarian carcinoma has be estimated at 30–50 cases per 100,000 women. Although less frequent than uterine tumors, however, these lesions are the leading cause of death from gynecological malignancy. Since causing only few, non-specific symptoms in early stages, they are commonly discovered at advanced stages (stages III and IV), when the disease has already spread beyond the ovaries. Only approximately 20 % of ovarian tumors are diagnosed while still in stage I. The 5-year survival rate at stages III and IV is approximately 15 %; for stage I it exceeds 90 % [7, 12].

Most ovarian tumors are benign; approximately 15 % are malignant, and 5 % are due to metastases. Malignancies are bilateral in more than 50 % of cases. Ovarian tumors can take origin from the surface epithelium of the ovary, from germ cells, or from the ovarian stroma. Epithelial lesions are the most common (70–75 % of all cases), and can be serous, mucinous, and endometrioid. Serous lesions are approximately 30 % of all ovarian tumors. The benign serous cystoadenomas appear as a cystic mass containing clear fluid, with thin interna septa. Wall nodulations are not frequent. There is no clear boundary between the US appearance of cystoadenomas and that of their malignant counterpart, cystoadenocarcinomas. As a general rule, the greater the amount of solid tissue within the lesion, the greater the possibility of malignant histology. Criteria suggesting malignancy are presence of thick septa, multiple papillary projections, solid portions within the mass, and detection of ascites. Mucinous neoplasms are approximately 20–25 % of all ovarian tumors. They too present as cystic masses with multiple internal septa; however, fluid contained within loculations tends to be more echogenic than in serous lesions, and fluid-debris levels can be frequently encountered. Rupture of these lesions can cause pseudomyxoma peritonei (Fig. 4) [7, 12]. Germ cell tumors account for approximately 10–15 % of all ovarian tumors, with over 95 % of them being benign cystic teratomas. A variety of other germ cell lesions can be encountered, all with higher malignant potential: the most common is the dysgerminoma, usually presenting as a solid mass. Mature cystic teratomas, commonly

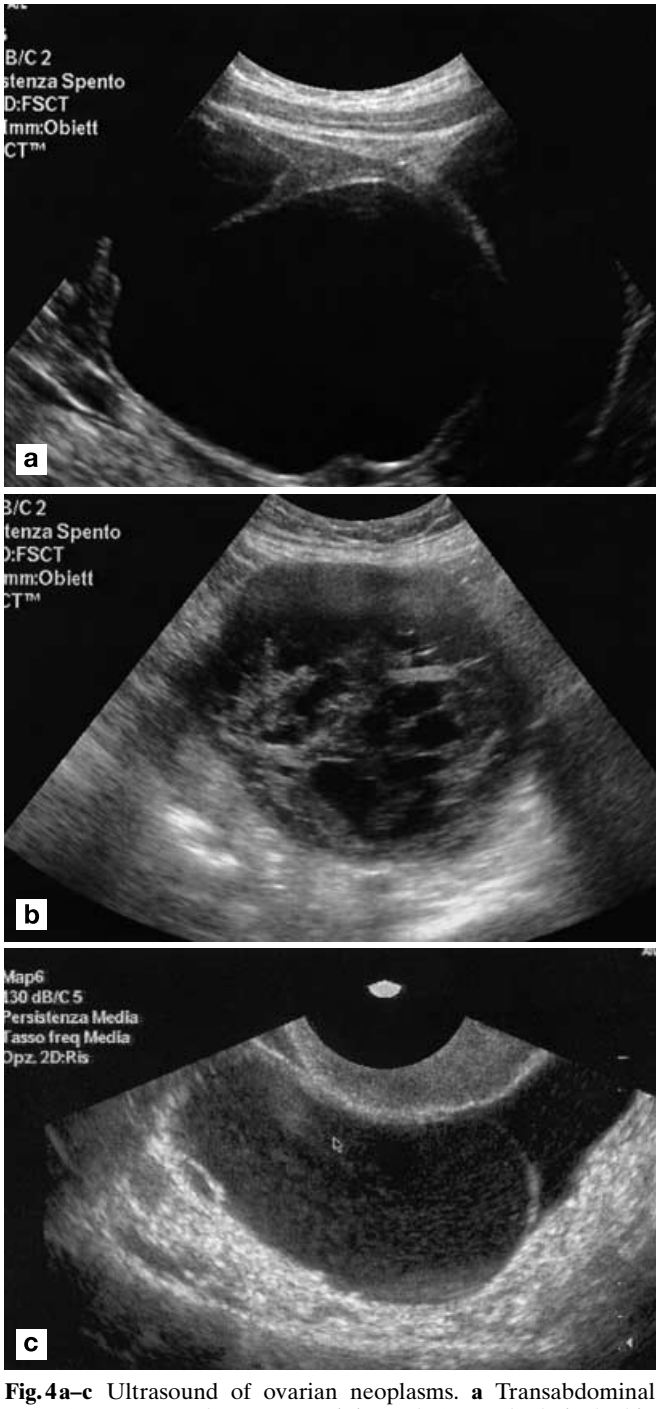


Fig. 4a–c Ultrasound of ovarian neoplasms. **a** Transabdominal scan of serous cyst adenoma containing only few and relatively thin septa, without parietal vegetations. **b** Transabdominal view of serous cyst adenocarcinoma characterized by multiple, thick, and irregular septa. **c** Transvaginal appearance of mucinous adenoma presenting thin septa and finely corpusculated fluid

known as "dermoid cysts," are benign and relatively frequent ovarian lesions. They are unilateral in 80–90 % of cases; a familial tendency has been noted. Ovarian dermoids are usually asymptomatic, and are often discovered during imaging studies or physical examinations performed for unrelated purposes. Transvaginal US has the capability to identify small, non-palpable ovarian dermoids [13]. The US characteristics of these lesions include a markedly hyperechogenic mass, with a structure similar to that of surrounding fatty tissue, cystic areas with round echogenic mural nodules, calcifications, tufts of hair, and fat-fluid levels. The feature that most commonly defines an ovarian mass as a cystic teratoma is focal or diffuse high-amplitude echoes that attenuate the US beam. These echoes may be due to calcifications, fat, or clumps of hair [13, 14, 15]. This pattern gives rise to the so-called tip-of-the-iceberg sign, a hyperechogenic image with posterior acoustic shadow which can be misinterpreted as a stool-filled rectosigmoid, thus causing false-negative results. The presence of hair can be particularly well identified with high-resolution transvaginal transducers as many, thin, hyperechogenic lines within the mass (Fig. 5) [16]. Sex-chord stromal tumors are hormonally active lesions that originate from the ovarian mesenchyma. They have a nonspecific solid US appearance in most cases. Among them are granulosa cells tumors, thecomas, fibromas, and Sertoli-Leydig cell tumors. Presence of a solid adnexal mass in a postmenopausal patient who is referred for uterine bleeding and has a thick endometrium at transvaginal US is virtually diagnostic for one of these lesions.

The neovascularity within a malignant neoplasm produces a significant increase in color Doppler flow signals (Fig. 6). This assumption has led many investigators to evaluate presence, spatial distribution, and prevalence of flow signals within ovarian masses in order to differentiate benign from malignant lesions. Although most malignant lesions appear well vascularized, with flow signals both at the periphery and in the central regions of the mass, and most benign tumors appear relatively poorly vascularized, a firm differential diagnosis based on flow detection seems not possible. In fact, avascular malignant tumors have been reported in the literature [17, 18, 19, 20, 21], and also benign hypervascular masses can be encountered [17]. Since the neovascularity within malignancies is made up of abnormal vessels, lacking smooth muscle within their wall, and contains multiple arterio-venous shunts, low-impedance flow is expected within such lesions. Initial studies measuring the resistive index (RI) and pulsatility index (PI) from vessels within the walls of malignant tumors have shown high sensitivity and specificity using values of RI lower than 0.4 and of PI lower than 1.0 [19, 20]; however, other studies have demonstrated significant overlap between values observed in benign and

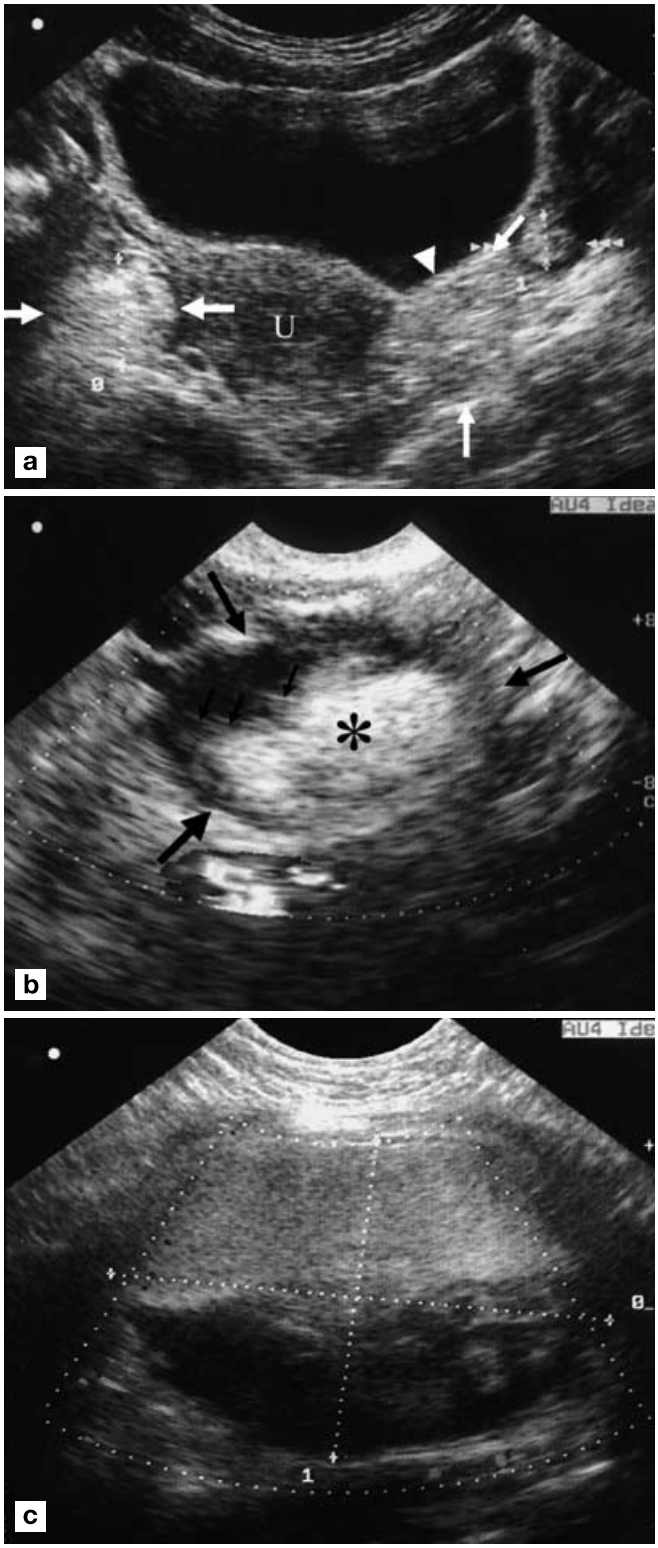


Fig. 5 a–c Different US appearances of ovarian dermoids. **a** Transabdominal scan of the pelvis showing bilateral, homogeneously hyperechogenic dermoids *(arrows)*. The left one is almost invisible, and only the slight anterior compression it causes on the wall of the urinary bladder *(arrowhead)* reveals it. **b** Transvaginal US of a small dermoid with a complex structure, made of a hyperechoic plug *(asterisk)* surrounded by hypoechoic fluid. Thin hyperechogenic lines representing hair are seen in it *(small arrows)*. **c** Transvaginal appearance of heterogeneous dermoid with fat–fluid level

malignant lesions [17, 22, 23], and reliance on flow parameters has been shown to be potentially misleading.

When facing an ovarian mass, preoperative determination of its nature is of utmost importance for proper patient management. Malignancy probability, in fact, affects surgical strategy (laparotomy vs laparoscopy), and even the choice of the surgeon (oncological specialist vs general). Together with measurements of tumor markers, US is the best diagnostic technique for this purpose. Scoring systems of the US images based on number and thickness of septa, presence and number of vegetations, and proportion of solid tissue within the mass have been proposed in order to standardize the interpretation of findings and the results of this technique [24, 25]. Although relatively good results can be obtained with analysis of the morphology and structure of adnexal masses, the combined use of all different US techniques, namely morphological assessment, color Doppler, and spectral analysis of flow signals, can be used together for this purpose. This seems to increase the specificity and positive predictive value of the US diagnosis [22, 26, 27]. This has been recently confirmed in a meta-analysis from 46 studies (5159 patients) in which significantly higher performances for combined US techniques were observed in comparison with each of the three techniques considered alone [28]. Artificial neural networks have been recently applied to prediction of ovarian malignancy in patients with adnexal masses and, based on the same set of US and demographic parameters, found to be more sensitive than conventional statistical methods [29].

Abnormal bleeding

Postmenopausal bleeding is a relatively common problem in women, and can be the presenting symptom of endometrial cancer, the most common pelvic malignancy [30]; however, only 10–20 % of women with postmenopausal bleeding have endometrial malignancy; the remainder have a benign cause for this symptom [31]; thus, accurate evaluation of the etiology of bleeding is needed. The most common cause of postmenopausal bleeding, in fact, is endometrial atrophy, with bleeding commonly due to superficial ulcerations of the atrophic

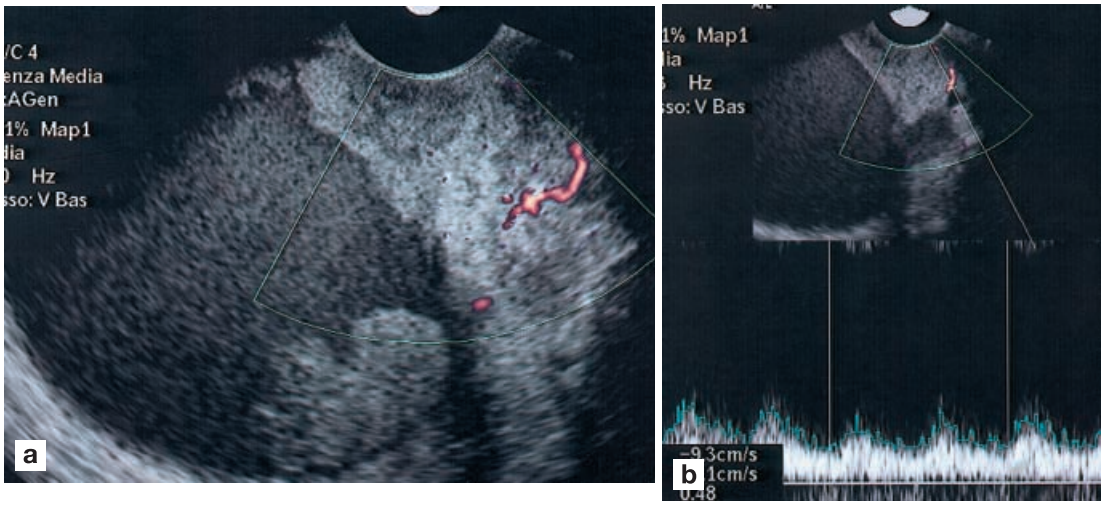


Fig. 6a, b Transvaginal color Doppler of large mucinous ovarian carcinoma. **a** The lesion has a mixed structure, with both solid and liquid components. Color flow signals with tortuous course are seen in the solid portions. **b** Spectral analysis reveals low-impedance flow pattern

endometrium. Other possible causes are polyps, hyperplasia, and endometrial carcinoma. It must be remembered that both polyps and hyperplasia can be premalignant lesions, and may contain foci of malignancy and progress to carcinoma. Transvaginal US has been proven able to evaluate accurately the thickness and echostructure of the endometrium and, together with sonohysterography, plays an important role in the management of endometrial disorders. In clinical practice, it is commonly employed for three main purposes: determining which patient should undergo endometrial biopsy; accurate analysis of the endometrium to detect polyps or submucosal fibroids; and local staging of myometrial invasion from endometrial cancer [31].

Numerous studies have examined the capability of sonography to identify echostructural changes of the postmenopausal endometrium and to differentiate the possible various pathological conditions. Although detection of cystic endometrial changes has been found to suggest polyps, identification of homogeneously thickened endometrium to suggest hyperplasia, and heterogeneous structural pattern to indicate suspicion of malignancy, sonographic findings have too large an overlap to allow a confident diagnosis to be made on US imaging alone [30, 32, 33, 34]. Furthermore, also Doppler studies of the endometrial vasculature have not been found helpful for this purpose, since no significant differences have been demonstrated between resistance and pulsatility indices in benign vs malignant causes of endometrial thickening [35, 36]. Sonohysterography provides exquisite demonstration of the endometrial cavity and is able to describe accurately the morphological characteristics of endometrial lesions; however, it cannot provide differentiation between benign lesions and malignancies with absolute certainty, and all women with endoluminal masses still require histological evaluation to verify the presence of malignant disease [5, 37, 38, 39, 40].

The clinical usefulness of US in patients with postmenopausal bleeding relies of the ability of this technique to measure accurately endometrial thickness. Using transvaginal measurements of the thickest point of the endometrium, from the anterior to the posterior endometrial–myometrial junction, US–pathological correlation studies have demonstrated that, considering a cutoff value of 4 mm, in patients with endometrial measurements below this point postmenopausal bleeding can be related to atrophy with a high degree of confidence. Hyperplasia, polyps, and carcinoma give rise to higher measurements (Fig. 7). The false-negative rate associated with a sonographic thickness lower than 4 mm appears to be as low as, or even lower, than the results of office endometrial biopsy or dilatation and currettage [30]. A strategy using US measurement of endometrial thickness as a first approach to the postmenopausal patient with uterine bleeding has been developed [30]. No further work-up is needed if the measurement is lower than 4 mm, assuming the bleeding is due to endometrial atrophy. If the endometrium is thicker than 4 mm, or if the measurements cannot be taken accurately, a sonohysterography is then performed. Patients with thin endometrium (a single layer measurement < 2 mm) do not undergo further studies. Patients with polypoid lesions or focal thickenings undergo biopsy under hysteroscopic guidance. Those with diffuse thickening are addressed to conventional biopsy or dilatation and curettage. This diagnostic strategy can save up to 46 % of biopsies [41], and a cost analysis has suggested that it is less costly than the use of biopsy as the first procedure [42].

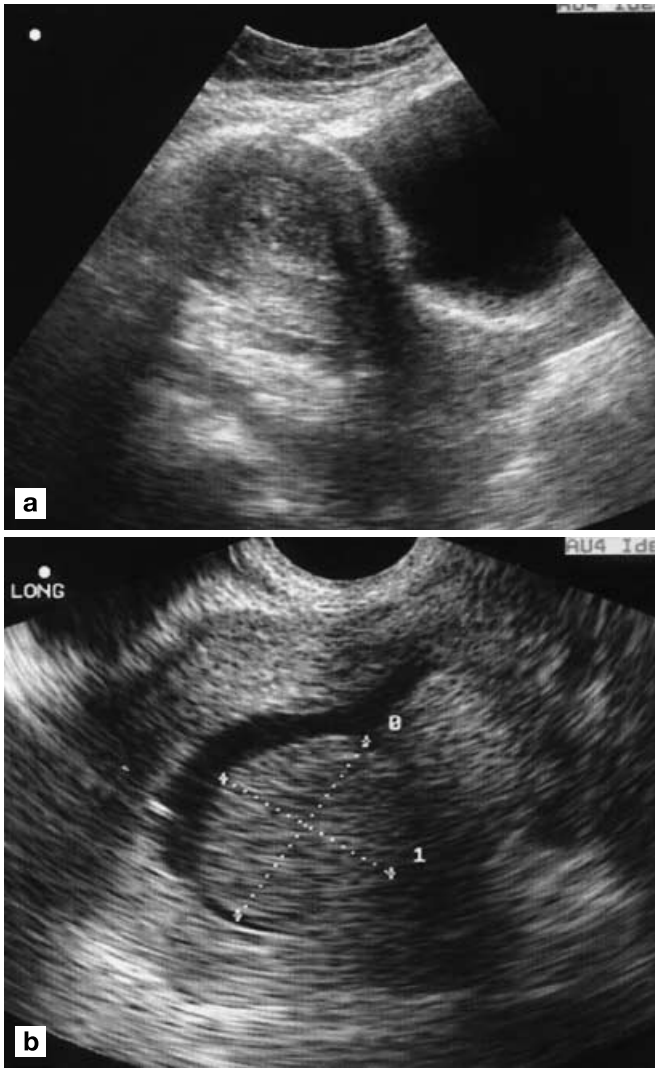


Fig. 7 **a** Conventional longitudinal scan of the pelvis in postmenopausal woman shows increased thickness of endometrial echoes. **b** Transvaginal US demonstrates a slightly dilated endometrial cavity and a large polypoid mass *(calipers)* within it

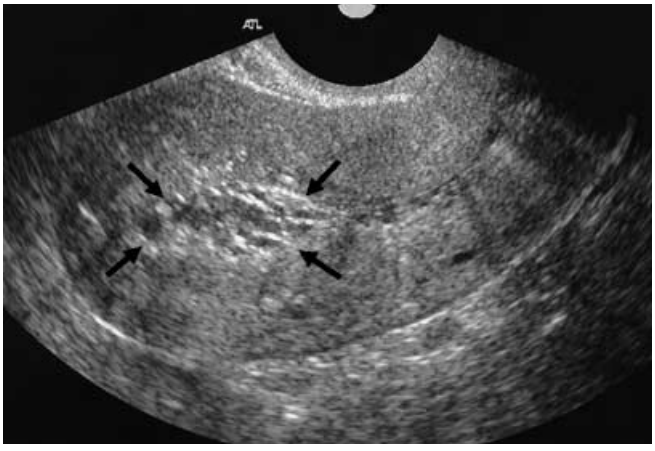


Fig. 8 Transvaginal scan in a patient taking Tamoxifen as adjuvant therapy for breast cancer. There is increased thickness of endometrial echoes, characterized by diffuse small cystic changes *(arrows)*

It must be remembered that this diagnostic algorithm applies only to postmenopausal women with bleeding and not to normal ones or to women taking medications. Women on hormone replacement therapy, in fact, tend to have increased endometrial thickness, and it is not possible, in them, to rely on the 4-mm threshold. Furthermore, the 4-mm value has not to be considered the upper limit of normal, but rather a reference point for clinical action in the specific setting of postmenopausal bleeding [30]. It is well known that non-bleeding women can have endometrial thickness greater than 4 mm. The decision to perform a biopsy in them has to rely not only on measurement, but also on clinical history and other US findings (echostructure, Doppler indices) or risk factors for endometrial cancer. Patients taking Tamoxifen as an adjuvant therapy for breast cancer undergo thickening of the endometrial image on transvaginal US. This is due to the development of endometrial hyperplasia with cystic changes and of endometrial polyps, as well as to occurrence of cystic changes at the endometrium–myometrium junction (Fig. 8). This finding has been postulated to represent adenomyosis [43]. Ultrasound is the best method to analyze the endometrium and to guide further diagnostic work-up in these patients [44].

The local extent of endometrial carcinoma is an important prognostic factor for the disease, and endovaginal US is considered an accurate technique for staging it (Fig. 9). Direct extension of the tumor into the myometrium can be assessed and measured; false-positive findings can be encountered, due to compression and thinning of the myometrium from large benign lesions that can be misinterpreted for myometrial invasion. Reported accuracies of transvaginal US in this field range from 84 to 98.6 % for depth of myometrial invasion, and from 93.5 to 95.65 % for extension to the uterine cervix [43].

Abnormal bleeding can be encountered also during the reproductive years. It can be classified as menorrhagia, when there is increased volume of menstrual flow, or metrorrhagia, when intermenstrual bleeding, at any time between normal menstrual periods, occurs (Fig. 10) [10].

The usual causes of menorrhagia are presence of submucosal fibroids, adenomyosis, or dysfunctional bleeding. Abnormal bleeding is said to occur in 30 % of patients with fibroids, and is thought to be related to vascular engorgement and/or erosion of the overlying endometrium. A description of the US appearances of these lesions is provided elsewhere in this article. Uter-

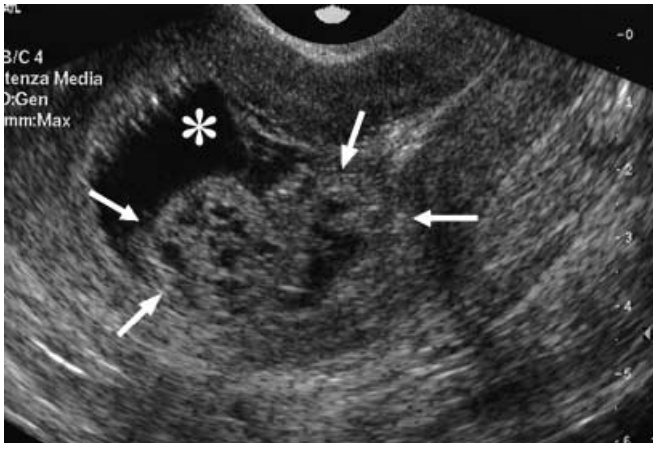


Fig. 9 Large endometrial carcinoma. Transvaginal scan shows a dilated cavity *(asterisk)* and a large heterogeneous mass projecting into it *(arrows)*. The margins between the mass and the underlying myometrium are indistinct. At surgery, infiltration of the deep endometrium was demonstrated

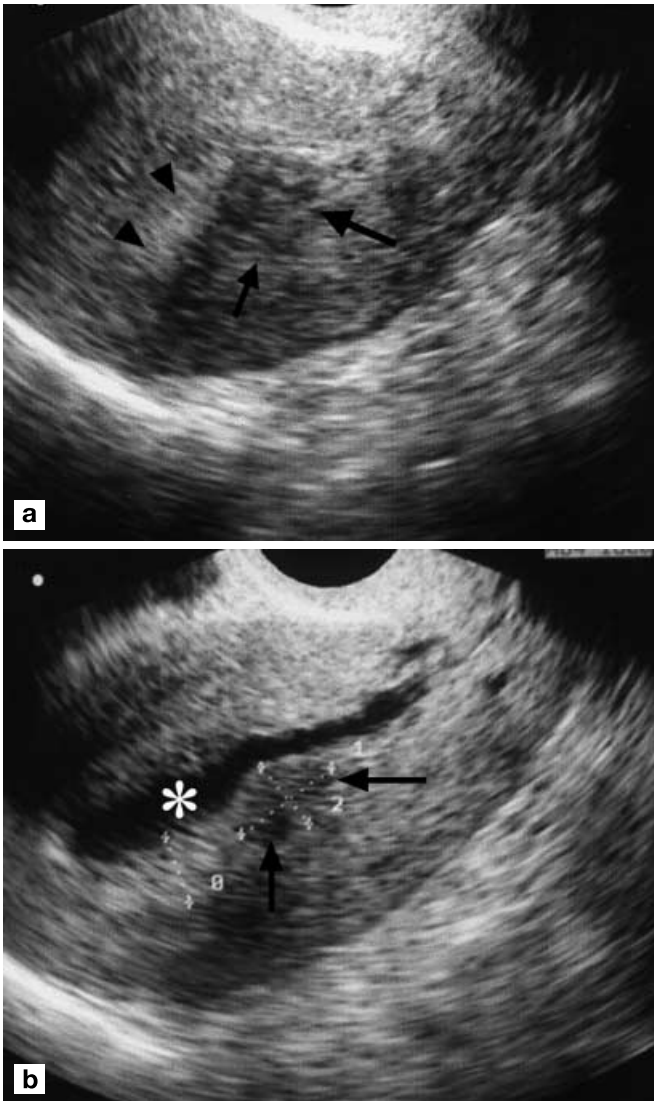


Fig. 10 a, b Transvaginal scan of patient with metrorrhagia. **a** Small hypoechogenic nodule *(arrows)* is seen in close relationship with the endometrial echoes *(arrowheads)*. **b** After distension of the endometrial cavity by hysterosonography *(asterisk)*, it is quite easy to demonstrate the lesion *(arrows)* as a small submucosal fibroid

ine adenomyosis is characterized by the presence of heterotopic endometrial glands and stroma in the myometrium, associated with adjacent smooth muscle hyperplasia. This condition in uncommon in nulliparous women, whereas it is more often encountered in multiparous women over 30 years of age. The most common complaints are menorrhagia (40–50 %), dysmenorrhea (15–30 %), and dyspareunia and pelvic tenderness (7 %) [10]. The US diagnosis of this condition is difficult and based on a variety of findings which may be very subtle: ill-defined areas of abnormal ill-defined myometrial echogenicity, heterogeneous myometrial echotexture, small myometrial cysts, echogenic nodules and striations, pseudowidening of the endometrium and poor definition of endometrial junction, and relative absence of mass effect. At Doppler evaluation lesions are vascularized and vessels appear less well organized than those in the normal myometrium [45, 46]. Careful analysis of these findings allowed Reinhold et al. to reach a value of 89 % of sensitivity and specificity for transvaginal US in this field [47].

Spotting at the time of ovulation is the most common cause of premenopausal metrorrhagia. The second most common cause is presence of endometrial polyps [10]. Such lesions are protruding stromal cores covered by mucosal surface which project into the endometrial lumen. They may be solitary or multiple, and may be sessile or polypoid on a stalk. Ultrasound findings include: an ovoid echogenic mass, best visualized in the first half of the cycle, when the endometrium is less echogenic; a cyst or a group of cysts in the endometrium; and a prominent feeding vessel at color Doppler. Hysterosonography is the best procedure for diagnosing such lesions. It allows to demonstrate accurately the focal nature of these lesions, as opposed to the diffuse endometrial thickening of endometrial hyperplasia. Polyps appear as echogenic masses projecting from the endometrial surface into the cavity, well outlined by the injected anechoic fluid (Fig. 11) [33, 34, 37, 38, 39, 40]. Color Doppler US can easily detect the feeding vessel, and this can be an additional feature that, in difficult cases, further confirms the differential diagnosis with hyperplasia. Differentiation of polyps from submucosal fibroids is based on differences in echotexture (the fibroid is hypoechoic, similar to the myometrium, whereas the polyp is hyperechogenic) and on demonstration of the

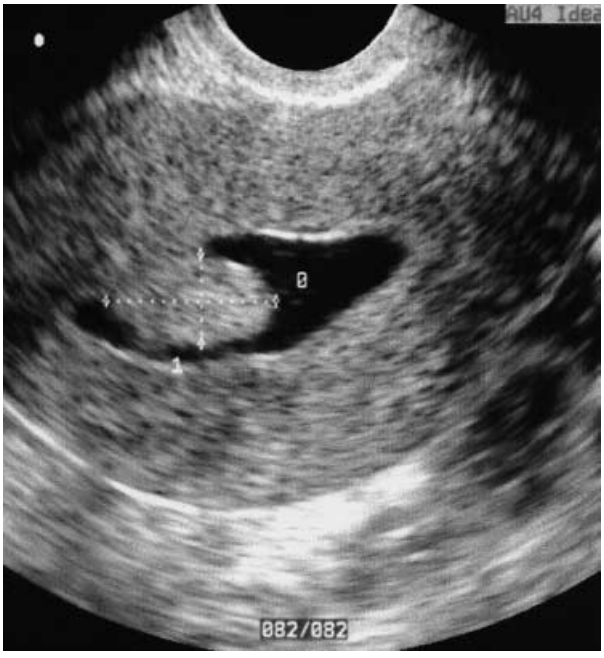


Fig. 11 Hysterosonogram of a 1.5-cm endometrial polyp *(calipers)*, well delineated by the hypoechoic saline injected within the endometrial cavity

endometrial mucosal surface which divides the fibroid from the endometrial lumen [40].

Pelvic pain

A large variety of pathological conditions, both acute and chronic, can cause pelvic pain; among them, there are also non-gynecological problem which are not addressed in this review. A correct approach to the patient with pelvic pain must include knowledge of clinical history and the results of the physical examination, as well as of an array of laboratory examinations (including a pregnancy test) which can help proper interpretation of the US results. Chronic pelvic pain can be a clinically difficult problem. Ultrasound can be useful for detection of lesions of pelvic organs such as uterine fibroids or endometriosis. Many cases, however, have no demonstrable cause. Pelvic congestion syndrome is a peculiar situation which can be well detected by US. Color Doppler US shows dilated, tortuous ovarian and uterine venous structures with slow flow. Although this is a relatively typical finding, and its association with chronic pelvic pain is well established, it must be noted that images of this kind can be detected also in asymptomatic patients [48]; thus, the clinical significance of dilated pelvic veins in absence of symptoms is still unclear.

Hemorrhagic physiological ovarian cysts, of follicular or corpus luteum origin, are probably the most common cause of acute pelvic pain. Ultrasound findings of hemorrhage depend on the age of the cyst, and include heterogeneous mass with internal echoes, thin septa, fluid-debris level, and retracting clot. Acute intracystic hemorrhage can appear with solid pattern, isoechogenic to ovarian parenchyma. When such a lesion is suspected on clinical and US grounds, short-term sonographic follow-up is usually able to demonstrate spontaneous disappearance of the lesion [49].

Ectopic pregnancy

Ectopic pregnancy is a very important cause of maternal death, inducing a tenfold increased rate of death risk over a normal pregnancy. The clinical diagnosis of this condition is not easy: The classic triad of pain, palpable adnexal mass, and abnormal bleeding is not always present, and may even lead to false-positive diagnosis of ectopic pregnancy. Women with a history of pelvic inflammatory disease, who had previous ectopic gestation or with an intrauterine device, can be considered at higher risk of developing an ectopic pregnancy; however, it must be stressed that in all women presenting with a positive pregnancy test and pelvic pain, adnexal mass and/or hemorrhage, an ectopic pregnancy must be considered as a possible diagnosis [50]. Ultrasound plays a pivotal role in clinical management of patients with suspected ectopic gestation. Since the occurrence of heterotopic pregnancy (i.e., presence of both an intra- and extrauterine pregnancy) is very rare, identification of an intrauterine pregnancy is the single most important finding for exclusion of ectopic gestation. It must be remembered that the decidual reaction induced by the ectopic can cause confusing findings at the level of the uterus. A firm diagnosis of intrauterine pregnancy can be achieved only by detection of the embryo in the gestational sac. Accurate analysis of the sac itself, with identification of a double echogenic external layer relating to the two rings of the decidua parietalis and decidua capsularis, is almost as accurate, even if a few false positives have been described in literature. An ectopic pregnancy may present with a large variety of US patterns. An extrauterine gestational sac containing an embryo is the most typical finding; however, solid and complex adnexal masses in conjunction with an empty uterus and a positive pregnancy test may be encountered. Such lesions are usually related to hemorrhage within the ectopic sac, or to an ectopic pregnancy ruptured into the fallopian tube. Free corpusculated fluid or pelvic blood clots are often associated [51, 52, 53]. Placental blood flow can be observed with endovaginal color Doppler imaging and can help in the diagnosis (Fig. 12) [54]. Patients who fail to demonstrate either an intrauterine pregnancy or an adnexal abnormality are particularly difficult to manage. They can have, in fact, a

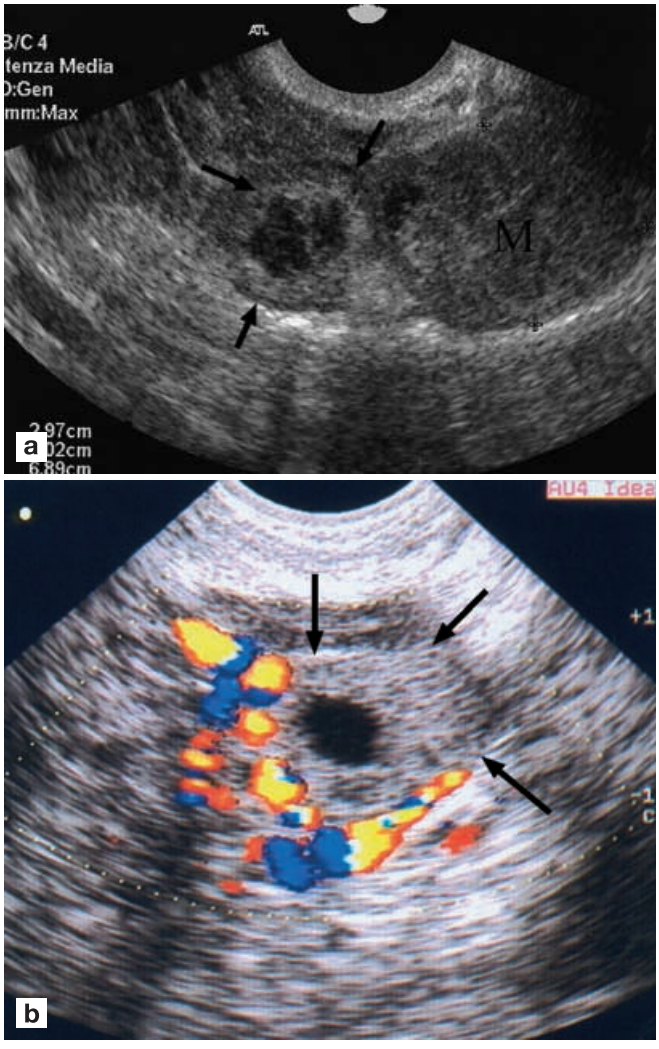


Fig. 12 a, b Transvaginal US in ectopic pregnancy. In **a**, an irregular extrauterine gestational sac is visible *(arrows)*, with some internal echoes, associated with an adnexal hemorrhagic mass *(M)*. In **b**, an extrauterine gestational sac *(arrows)* is seen, surrounded by a ring of color flow signals

normal pregnancy too small to be seen sonographically, a recent abortion (with still measurable hCG levels), or indeed an ectopic gestation. Correlation of US images with quantitative measurements of hCG can help in classifying and properly managing them. In doubtful cases, serial determinations of hCG and repeat US studies, even at short term, are needed to assess accurately patient's status [50, 55].

Ovarian torsion

Ovarian torsion accounts for approximately 3 % of gynecological emergencies. It can be difficult to diagnose

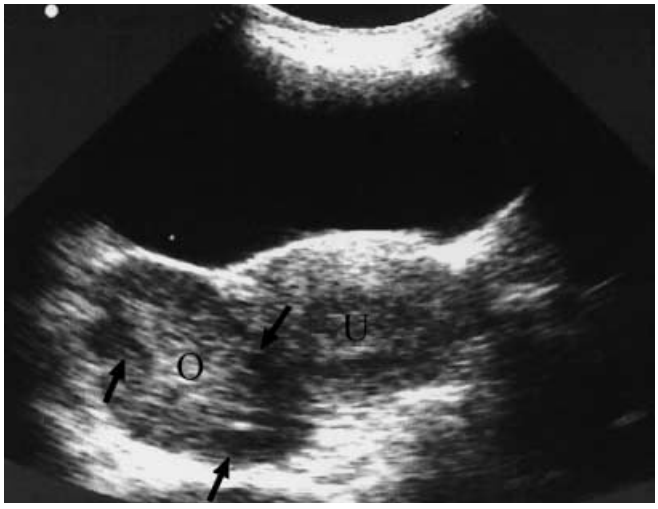


Fig. 13 Conventional US of the pelvis in a young patient with acute torsion of the right ovary. The right ovary *(O)* is enlarged, with small follicular images at the periphery. *U* uterus

on clinical grounds because it may be accompanied by symptoms that mimic other causes of acute abdomen. Torsion is more common in premenopausal patients, and is often associated with an ovarian mass which acts as a lead point. The US appearance of ovarian torsion varies according to the degree of vascular compromise and presence of an adnexal mass. Typical findings include an enlarged ovary with a solid, hypo-, or hyperechogenic structural pattern. A specific finding is the presence of many small follicular images at the periphery of an enlarged ovary (Fig. 13) [56]. The fallopian tube is torsed with the ovary, and may be seen as a hypoechoic structure around it [57]. Free pelvic fluid is commonly associated. Color Doppler sonography has been shown to be of help in the diagnosis of this condition, since absence of vascular signals within the mass is diagnostic; however, findings vary according to the degree of vascular involvement: initially, there is lymphatic and venous vascular compromise, and arterial damage is only late and associated with high degrees of torsion. Some authors, in fact, have found vascular signals within surgically proven torsed ovaries [58, 59]. This may reflect early or partial torsion and occlusion of only venous flow, with preservation of arterial blood supply. It may be due also to the fact that the ovary has double arterial vascular supply, whereas an episode of torsion may involve, or involve predominantly, only one vascular pedicle. Presence of central venous signals in tubo-ovarian torsion is suggested to be an indicator of ovarian viability [58].

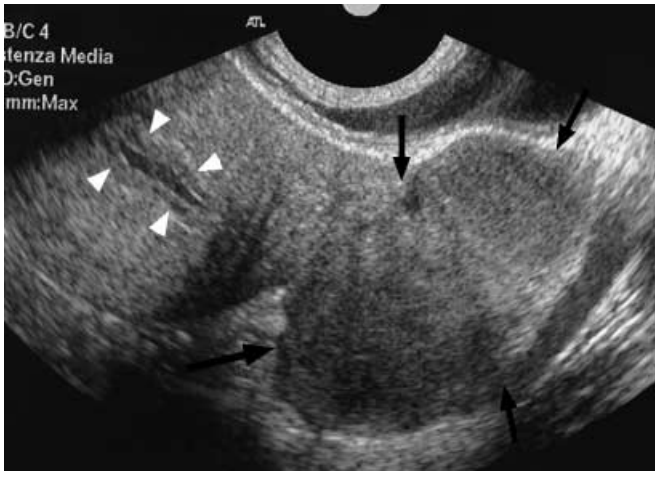


Fig. 14 Transvaginal imaging of patient with pelvic inflammatory disease. Ultrasound shows slight dilatation of the endometrial cavity, which contains echogenic fluid, and is surrounded by slightly thickened endometrium *(arrowheads)*. In the left adnexal region there is a large solid mass, a tubo-ovarian complex *(arrows)*. Tenderness was elicited in this region by positioning of the US transducer

Pelvic inflammatory disease

Pelvic inflammatory disease is probably the most common cause of acute pelvic pain, at times presenting as an acute surgical abdomen. Ultrasound findings vary according to the severity of the disease. In early conditions, without complications, US may be normal. In more advanced stages, findings include free pelvic fluid, endometrial thickening, distension of the endometrial cavity by fluid or gas, and indistinct borders of the uterus and ovaries. Infections ascending from the uterus to the salpinx and ovary may cause tubo-ovarian complexes, a combination of enlarged, inflamed ovaries and dilated, inflamed tubes (Fig. 14), or frank tubo-ovarian abscess. A tubo-ovarian abscess appears as a cystic mass, with fluid-debris level, echogenic fluid, or internal gas. Outer margins can be indistinct, and free fluid in the cul de sac is commonly associated. In patients not responding to medical therapy, US can be used as a guide to transvaginal drainage of these lesions [49, 51, 60].

Female infertility

Infertility is a complex matter that requires a multidisciplinary clinical approach as well as comprehensive management of both components of the infertile couple. Although a female cause for infertility can be found in up to 60 % of cases, in fact, a male problem or factors involving both partners are relatively frequent. The most common gynecological problems related to infertility include tubal disease and endometriosis (30–50 %), anatomic or functional ovarian disorders (45 %), and cervical factors (10 %); in addition, it must be noted that 5–10 % of cases of infertility are unexplained [61, 62].

Ultrasound is commonly regarded as the first approach to the infertile patient and is employed for four main purposes: identification and documentation of the integrity of the reproductive tract as a conduit for the passage of gametes and embryos; detection of pathological processes that may be a cause of or a contributing factor to infertility; monitoring cyclic changes of the uterus and ovary to document normal physiology or pathological situations; and monitoring and guiding infertility treatment [63, 64].

Uterine causes of infertility

Both functional and morpho-structural lesions of the uterus can affect female fertility. Ultrasound can easily demonstrate the presence of pathological changes of the uterus which can affect both passage of gametes and implant of the fecundated ovum. Although fibromyomas and polyps are not, in themselves, proven causes of infertility, they merit diagnosis and treatment before fertility management is pursued. Conventional US can often demonstrate them; however, better depiction of the relationships of fibromas with the endometrial surface can be obtained with the use of hysterosonography. Distension of the endometrial cavity by the hypoechoic saline, in fact, allows accurate delineation of even small submucosal lesions. Also endometrial polyps can be easily detected by this technique. In addition, the use of color Doppler helps in the differential diagnosis between them and diffuse hyperplasia through demonstration of flow within the stalk of the polyp. Intrauterine synechiae can be seen as hypoechoic lines disrupting the echogenic endometrium, but are difficult to diagnose by conventional US. In patients with a positive clinical history (previous currettage, endometritis, septic abortion), a hysterosonography is needed, and they can be more easily seen as echogenic bands extending from one endometrial surface to the other. Congenital uterine anomalies are an important cause of infertility or of early spontaneous abortion [65]. Ultrasound, especially using the transvaginal approach, plays a very important role in their diagnosis given its capability to evaluate accurately the shape of both the uterine body and the endometrial cavity. Different findings can be observed according to the different pathological conditions. In patients with complex anomalies associated with vaginal agenesis or imperforate hymen, a hematocolpos is commonly seen, often with associated hematometra or hematosalpinx [62]. A complete duplication anomaly, such as uterus didelphys, can be diag-

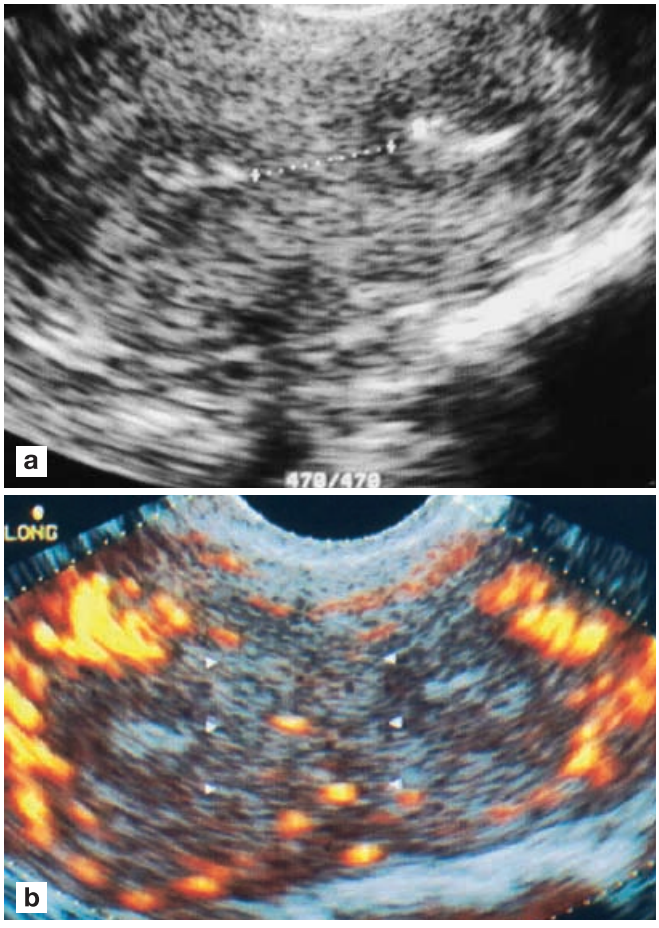


Fig. 15 a, b Transvaginal US of septate uterus. In **a**, the two cavities are well seen, and the distance between them is measured. **b** Power Doppler US demonstrates that the septum between the two cavities *(arrowheads)* is relatively poorly vascularized. This explains, at least in part, the high complication rates of pregnancies in septate uteri

nosed by detecting two separate and divergent uterine horns, with a deep fundal cleft between the two hemiuteri and a wide angle between the two cavities. Measurement of the angle between the two cavities and analysis of the fundal shape helps in the differentiation between bicornuate uteri and septations anomalies. This differential diagnosis is important, since septate uteri, which seem to have higher complications rate, are amenable of hysteroscopic treatment (Fig. 15). Bicornuate anomalies have an angle higher than 105°, whereas septate uteri have an angle lower than 75°; in patients with intermediate values, associated demonstration of the cleft of the uterine fundus can improve the diagnostic accuracy up to 90% [66].

Fallopian tubes

Lesions of the fallopian tubes account for approximately 50% of causes of infertility. A pathological tube can be detected by US only when distended by fluid, such as in cases of obstruction. Analysis of fluid echogenicity can help in differentiating a simple sactosalpinx from a tubal abscess. Injection of echogenic contrast material under real-time US control, the so-called sonohysterosalpingography, has been recently proposed as a means to assess tubal patency without the use of ionizing radiations. This test can be performed in an outpatient setting and has high patient acceptance. Passage of contrast through the tubes is detected by means of color or pulsed Doppler techniques, as well as of identification of spillage of contrast in the peritoneal cavity: These criteria have been used to recognize patency. Good correlation with the results of traditional techniques has been demonstrated by many authors, with values up to 90% [67, 68, 69, 70]; however, it must be remembered that a patent tube does not mean a normally functioning tube, and that fine parietal alterations cannot be detected by this test. Conventional hysterosalpingography can still be needed for accurate delineation of the tubal anatomy in selected indications. More recently, sonohysterosalpingography is being performed with the use of contrast-specific scanning techniques which allow good identification of flowing contrast and almost complete cancellation of static tissues. This provides better delineation of the tubes, with higher anatomic detail, as well as easier detection of peritoneal spillage (Fig. 16a, c). Although it is only at early stages of development, this seems a promising technique which will possibly reduce further the need for conventional hysterosalpingography.

Peritoneal causes

Also lesions involving the peritoneum can affect fertility. Adhesions from previous surgical interventions, pelvic inflammatory disease, or endometriosis, can cause impeded passage of the ovum into the tube. Adhesions are difficult to see directly by US; they can be inferred from secondary signs such as presence of loculated fluid or distortion of pelvic organs and structures. Peritoneal inclusion cysts can mimic a large variety of other pathologies, including a dilated salpinx, paraovarian cysts, and ovarian tumors. The correct diagnosis can be suggested by a positive clinical history or by showing that the collection of fluid conforms to the shape of the peritoneal cavity [71]. Pelvic endometriosis is another frequent cause of infertility, and can be found in up to 20% of patients undergoing laparoscopy for this problem [72]. Although the association between endometriosis and infertility is well established, the causal mecha-

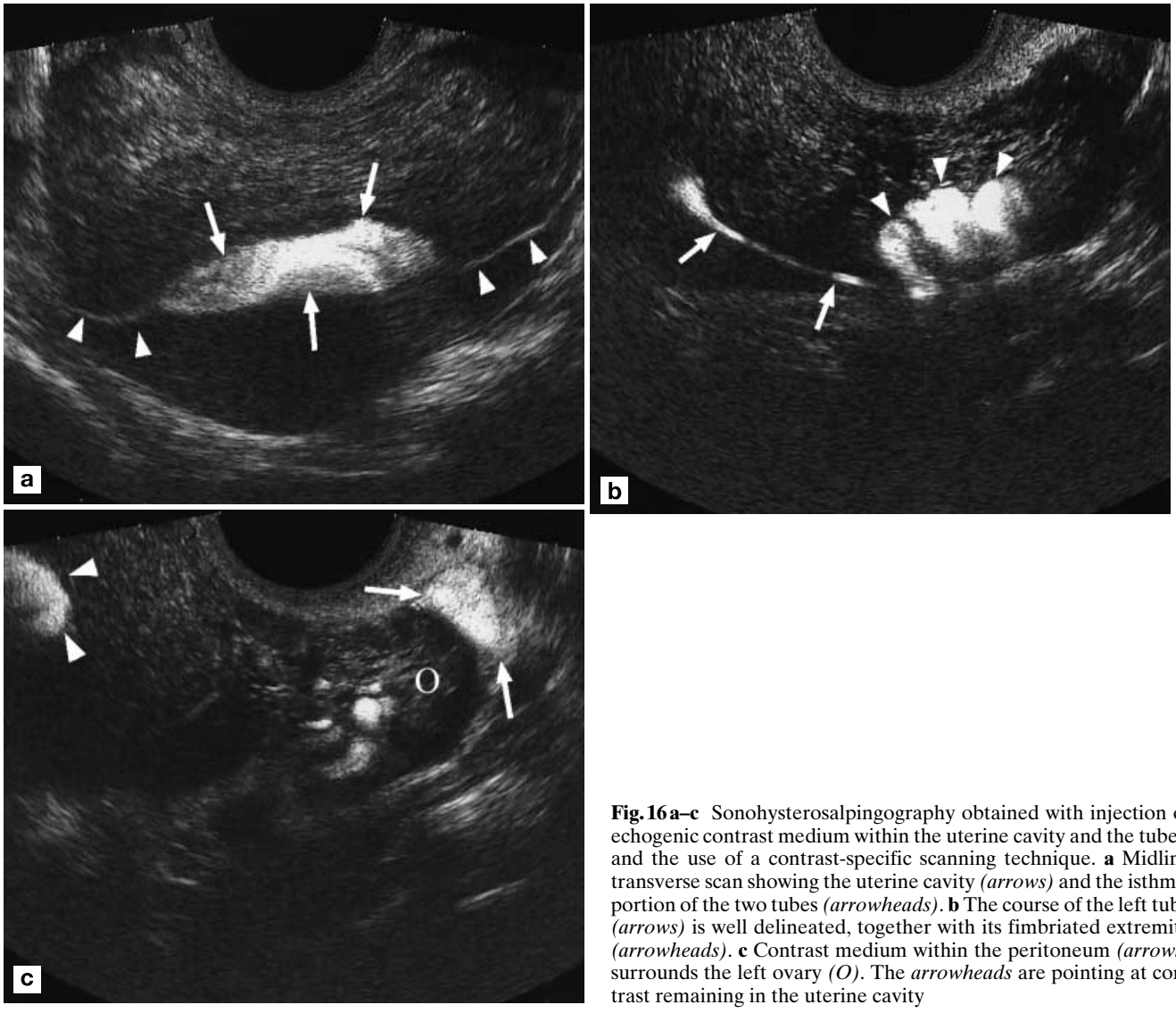


Fig. 16 a–c Sonohysterosalpingography obtained with injection of echogenic contrast medium within the uterine cavity and the tubes, and the use of a contrast-specific scanning technique. **a** Midline transverse scan showing the uterine cavity *(arrows)* and the isthmic portion of the two tubes *(arrowheads)*. **b** The course of the left tube *(arrows)* is well delineated, together with its fimbriated extremity *(arrowheads)*. **c** Contrast medium within the peritoneum *(arrows)* surrounds the left ovary *(O)*. The *arrowheads* are pointing at contrast remaining in the uterine cavity

nism is still debated. The most accepted explanation is that endometriomas and adhesions cause distortion of pelvic anatomy, with subsequent impaired ability of the tubes to capture ovum. Other proposed mechanisms are related to autoimmunity, to peritoneal fluid factors, or to disorders of the axis hypothalamus–hypophysis–ovary. Ultrasound is the most common imaging procedure to evaluate suspected endometriosis, although its role is mostly limited to evaluation of endometriotic cysts. Its capability in the detection of small implants and adhesions is, in fact, limited. Endometriomas exhibit a variety of sonographic appearances, the most common being a pelvic mass with thick wall and an internal structure made of diffuse low-level echoes; they can be bilateral. Endometriomas rarely present as anechoic masses mimicking a simple ovarian cyst. Multilocular lesions can be encountered, usually made of single cysts grouped together. Between these loculi, septa can be both thin or thick, but wall nodulations are relatively unusual. In the absence of wall nodulations, a multicystic pelvic mass is more commonly due to endometriosis than to an ovarian neoplasm (Fig. 17). Echogenic foci have been observed within the wall of endometriomas. These findings are more echogenic and smaller than true wall nodules and, in a recent series [73], they have been found to be the highest single diagnostic predictor for endometrioma. It has been postulated such findings are due to cholesterol deposits in the endometriotic cyst wall [73, 74]. Heterogeneous-appearing hemorrhagic cysts can be confused with endometriomas due to the presence of internal strands of fibrin and fine echoes due to blood; however, these lesions resolve on follow-

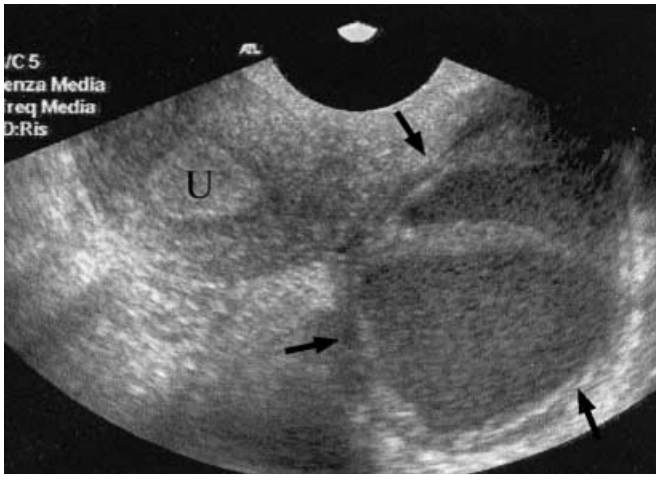


Fig. 17 Transvaginal US of endometrioma. The lesion *(arrows)* has a multiloculated appearance and contains finely corpusculated fluid. *U* uterus

up examinations, and endometrioma can thus be ruled out. It must be remembered that MR imaging has been proven very useful and more specific than US for the diagnosis of endometriomas; thus, it is indicated as a problem-solving tool in doubtful cases.

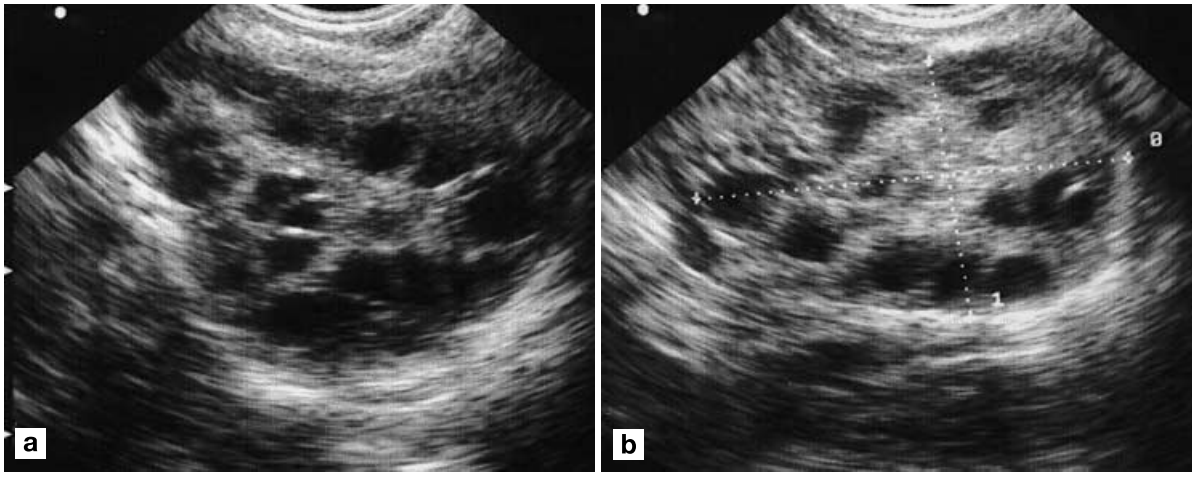
Ovarian cause of infertility

A large variety of ovarian pathologies, mostly functional, can affect female fertility. Ultrasound can play a role in this field given its capability to analyze the morphology and structure of these organs and to detect pathological changes affecting them. Bilateral space-occupying lesions, although rare, can be encountered, and explain poor ovarian function. The clinical triad of obesity, hirsutism, and oligomenorrhea constitutes the Stein-Leventhal syndrome. These conditions are encountered in up to 21 % of patients referred to a fertility practice, and a familial tendency has been encountered. Classically, the ovaries are enlarged, with small, multiple, peripheral cysts, without a dominant follicle. An increased echogenicity of the inner structure of the ovary has been observed and related to fibrosis of the ovarian stroma (Fig. 18); however, large ovaries without visible cysts, or even small ovaries, can be encountered in these patients, and then close correlation of US with clinical and laboratory findings is needed for proper patient diagnosis and management [75, 76, 77]. Ultrasound follow-up during treatment can show a decrease in ovarian volume. A variety of pathological conditions, either primary, such as precocious menopause or premature ovarian failure, or secondary, such as malnutrition, stressful conditions, or professional athletic training, can lead to conditions of dysovulation. Little is revealed by US in these cases, and only small ovaries, with few small follicular images, are seen.

US monitoring of the infertile patient

In the infertile patient, one of the most powerful uses of US is monitoring the various treatment techniques. Ultrasound can be used to follow the patient over time to observe follicular development and to demonstrate the influence of increasing estrogen on the endometrium [64]. Furthermore, it can be used to guide interventional maneuvers such as oocyte retrieval and transfer of embryos into the endometrial cavity.

Fig. 18 a, b Transvaginal US in two patients with Stein-Leventhal syndrome shows enlarged ovaries, with many small peripheral follicular images, absence of a dominant follicle, and increased echogenicity of the ovarian stroma



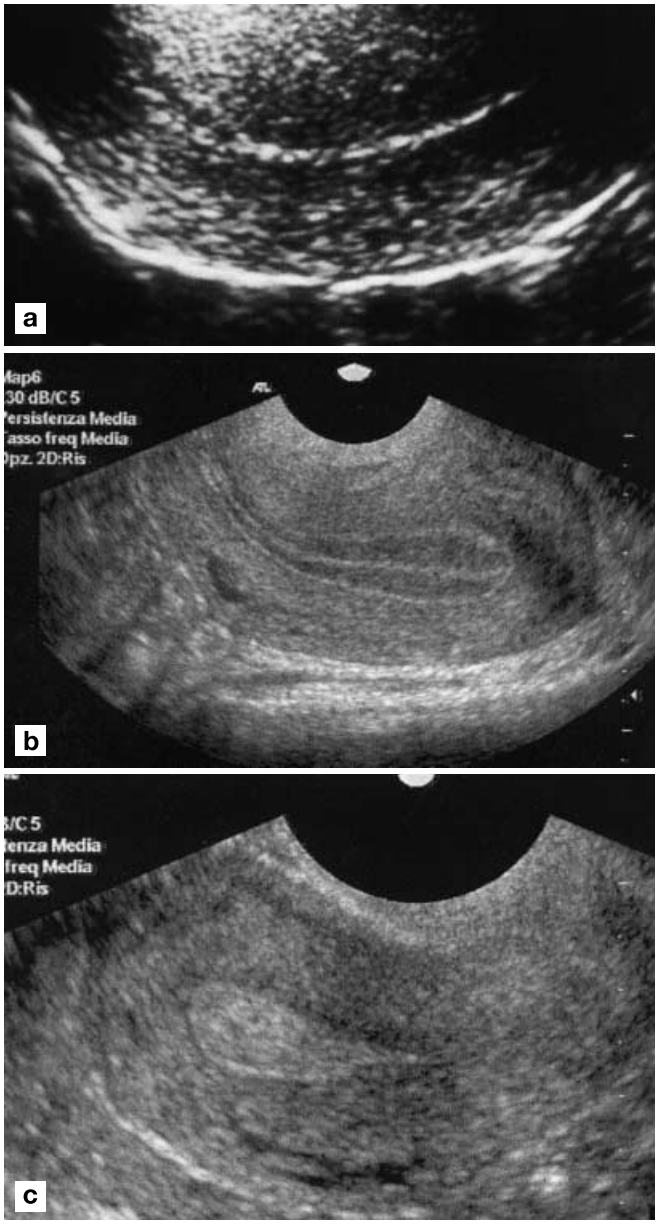


Fig. 19 a–c Ultrasound monitoring of the uterine structure. **a** In the postmenstrual period the endometrium appears as a single echogenic central line. **b** In the proliferative phase, the endometrium gets thicker and assumes a structure made of three, alternate hyper–hypo–hyperechogenic lines. **c** The secretory phase is characterized by a thick, homogeneously hyperechoic, endometrial appearance

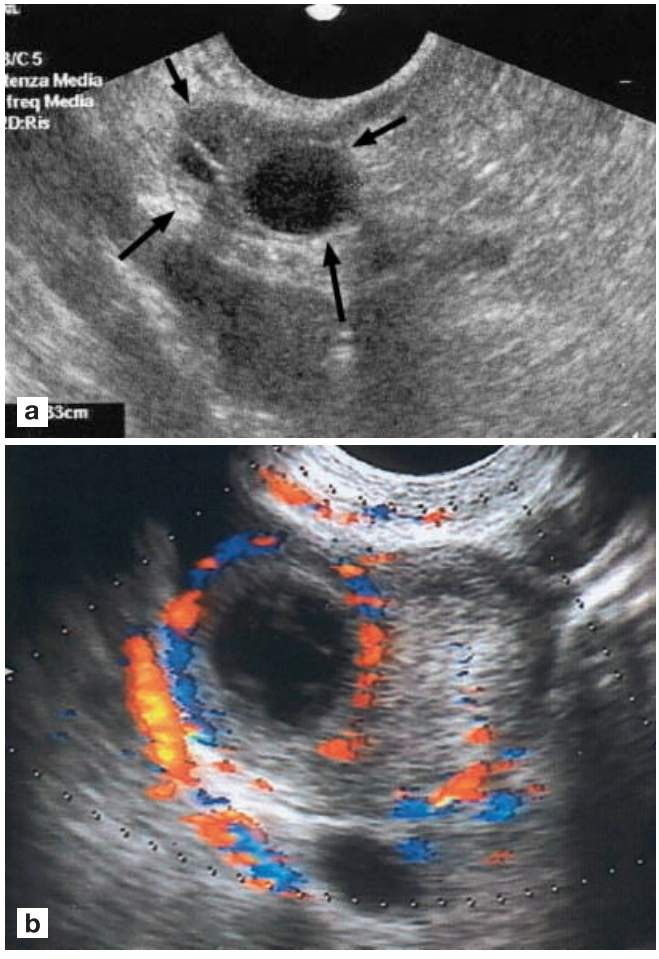


Fig. 20 **a** Transvaginal US of a normal ovary *(arrows)* containing a follicle 13 mm in diameter. **b** Transvaginal color Doppler showing a ring of neovascularization surrounding a normal corpus luteum

Uterine monitoring

Transvaginal US can accurately analyze both thickness and structure of the endometrium. In normal cycles, three different patterns are demonstrated over time:

1. The postmenstrual endometrium has a single echogenic line.
2. In the proliferative phase, the endometrium gets thicker and develops a structure made of three, alternate hyper–hypo–hyperechoic lines.
3. Progression to the secretory phase leads to a homogeneous hyperechogenic endometrial appearance (Fig. 19).

In patients undergoing in vitro fertilization and ovulatory induction, there is a direct correlation between the implantation rate and at least an 8-mm trilaminar endometrial pattern. Also the uterine blood supply undergoes changes along the menstrual cycle. In the early follicular phase high-flow impedances are observed; thus, resistances decrease following the rise in estrogens, and there is a transitory rise in resistance at midcycle followed by further fall to the lowest value 7 days after ovulation. Prior to the menstruation, the imped-

ance rises as the ovarian hormone levels fall. Also uterine blood flow relates to pregnancy rates. Patients undergoing in vitro fertilization who present with high uterine flow resistances prior to embryo transfer fail to conceive [63].

Ovarian monitoring

Ultrasound is commonly employed to monitor the process of folliculogenesis both in normal and stimulated cycles. In natural cycles, observation of a developing follicle and prediction of ovulation allow optimal timing of procedures such as post-coital testing, hCG administration, intercourse, insemination, and ovum collection. During the 5 days before ovulation the dominant follicle grows rapidly, but size is not a good predictor of ovulation, since rupture occurs at a wide range of values (13–30 mm, mean 21 mm; Fig. 20a). Presence of a hypoechoic line around the follicle or of a small parietal mass thought to represent the cumulus oophorus have been described as ovulation precursors, but are not frequently observed. At ovulation, the follicle usually disappears and fluid is observed in the cul-de-sac. At the follicular site, the corpus luteum appears as an irregular structure containing a small quantity of fluid, internal echoes, and a thick wall [78]. In stimulated cycles, US is used to document the number and growth of follicles; together with hormonal measurements, it allows identification of optimal timing for triggering ovulation, oocyte retrieval, or intrauterine insemination. Furthermore, in cycles with hCG stimulation, US detection of too many follicles may induce hCG withholding to prevent ovarian hyperstimulation syndrome. When ovarian hyperstimulation occurs, US is used to grade disease severity through measurements of ovarian size, detection of ascites, and analysis of renal flow resistances [63, 64]. Blood flow in the ovulating ovary decreases throughout the menstrual cycles. At ovulation, there is dramatic increase of blood flow velocities in vessels surrounding the corpus luteum due to the development of new vessels with low impedance waveforms (Fig. 20b). In patients undergoing in vitro fertilization, a low ovarian impedance seems to correlate directly with pregnancy rates [79].

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