Doppler velocimetry

Introduction:

Christian Johann Doppler (1803-1853) was the first, to describe Doppler phenomenon which was named after him. Doppler studied the light emitted by stars and observed that the light, from a star moving away from earth turned to red whereas that emitted from an approaching star turned blue. In 1842, he postulated that there is a change in light color (i.e. frequency of light wave) with the change in position in relation to the observer. This frequency change is called Doppler effect or shift. This effect was applied to acoustic waves by Buys Ballot (1817-1890) and introduced in medicine to detect blood flow pattern in superficial arteries in 1957 by Satomura, while the first report in use of Doppler to measure fetal blood flow was by Fitzgerald and Drumm in 1977 ***(McParland and Pearce, 1990)***.

Physics of Doppler:

Doppler velocimetry is a non invasive technique that uses high frequency sound for investigation of blood flow. The basic principle used in Doppler examination is the Doppler shift or effect ***(McMichael and Stiles, 2008)***.

If the ultrasound beam is directed at a moving structure, the returning echoes will have undergone a frequency, shift or Doppler shift (Doppler effect) if a source of sound is moving with a velocity "V", the number of wave lengths which reach an observer per second increases as the source of the sound approaches the observer, thus the (tone) of sound appears to increase. Conversely, if the source of sound is moving away

from the observer, fewer wave lengths per second will reach the observer and the pitch of sound therefore falls ***(Nagai and Hayashi, 2008)***.

In other words echoes from stationary boundaries are returned with the same frequency as the emitted beam, where as echoes from moving particles such as a group of red blood cells undergo a frequency change (Doppler shift which is proportional to the velocity of moving particles ***(Nagai and Hayashi, 2008)***.

Diagnostic Doppler Techniques:

I. Continuous wave technique (CW):

In this technique, two crystals are used, one as a transmitter and the other acts as a, receiver. This technique is cheap, easy to operate, portable, can measure, high velocity flow even in deep vessels and low output sound intensity. However, it does not permit visualization of the sound beam as it crosses the tissues or of the blood vessels themselves. Also, it cannot differentiate echoes from multiple vessels in different depths along the beam as signals are obtained from all moving structures in the line of the Doppler beam ***(Azran et al., 2004)***.

II. Pulsed wave technique (PW)

In this technique ultrasound waves are produced in pulses and received by the same crystal. This technique has the advantage of determining the depth from which echoes should be received. The area from which echoes will be processed is called the sample volume.

Using this technique, echoed from certain vessel can be processed without interference of other nearly vessels. This technique is used in combination with real time B-scan ultrasound machine, the so called Duplex ultrasound to measure blood flow pattern in deep vessels. The

combined action between pulsed Doppler and real time ultrasound can be controlled either mechanically or electronically. In the mechanical method, the operator - determines the vessel of interest at time scan and then freezes the image and switches on Doppler waves to sample it. Now, the electronic controller made the operation easier as alternation is automatic ***(Zhang et al., 2005).***

III. The Duplex scanner:

The combination of real-time imaging and Doppler techniques is referred to as duplex scanning. Whereas ultrasound beam moves rapidly in order to create a real-time image, it must dwell for a much longer period in one orientation in order to obtain Doppler information. Typical combinations might be 5 MHz for imaging together with 3 MHz Doppler for trans-abdominal obstetric Doppler or 7-10 MHz for imaging and 5 MHz for Doppler for transvaginal probes ***(Rubin et al., 1995).***

IV. The color flow Doppler:

Doppler shifts are not restricted to a single volume as in pulsed Doppler but rather applies to a large region. Each ultrasound beam is divided into blocks and echo signals returning from each block are examined for evidence of Doppler shift. If a shift is detected, a color (blue or red) is superimposed on the underlying image ***(Oddershede et al., 2008).***

V. The power Doppler:

In power Doppler, the total signal level across all frequencies at each depth is displayed. One advantage of it is the signal-to-noise ratio which is normally better than that of its color flow counterpart. This improved

signal-to-noise ratio will mean that small vessels can be imaged which are otherwise invisible to ultrasound ***(Yoo et al., 2007).***

❖ **Doppler velocimetric measures**

Using Doppler ultrasound technique, much useful information about the blood flow pattern in blood vessels are obtained which are important - in reaching the diagnosis and planning the treatment of many obstetric and gynecological conditions. These measures depend on the maximum frequency shift during the cardiac cycle (Maximum systolic flow, A), minimum frequency shift during the cardiac cycle (End diastolic flow, B), the mean value of frequency shift throughout the cardiac cycle (Mean), the angle of incidence (0) and then diameter of the blood vessel ***(Rubin et al., 1995).***

The following indices were developed to represent flow:

Resistance index = (A-B) /A

This index indicates the state of peripheral resistance in the vascular bed distal to the point of measurement. The index value decreases as the peripheral resistance decreases and when the end diastolic flow is approaching zero, the index approaches unity ***(Gong et al., 2005)***.

Pulsatility index = (A-B) / Mean

The mean is calculated by the Doppler machine and thus, to obtain accurate measures, the frequency shift should be processed in high accuracy; so this index may be the most difficult to measure ***(Gong et al., 2005)***.

Systolic-diastolic (S/ D) ratio=A/B

This ratio describes the rate at which the flow velocities fall away during diastole, this closely corresponds to the peripheral resistance to the blood flow beyond the measurement point. Resistance index make use of the same parameters as A/B ratio, but expresses the values in a more convenient form ***(Gong et al., 2005)***.

Diastolic to average (P/A) ratio=D/A

This index is introduced by ***Maulik et al., 1982*** and claimed to be more informative about the end diastolic flow abnormalities.

However, it is not confirmed to be superior to other indices ***(McMichael and Stiles, 2008)***.

Calculation of velocity

If the angle of incidence (0) is measured, the blood velocity inside the vessel can be measured. However, in practice the measurement of (0) is difficult and velocity measurement is reliable only from fetal descending aorta. So the most commonly used measures are those not depending on the angle measurement ***(McMichael and Stiles, 2008)***.

Volume flow calculation

The volume of flow is calculated by multiplying the velocity by the cross sectional area of the vessel. Besides the difficulty in measuring the angle of incidence, measurement of the cross sectional area is difficult due to:

i- Diameter measurements are made by means of on screen calipers to the nearest millimeter.
ii- The diameter has to be squared to get the cross sectional area of the vessel so the error will be squared.

iii- The cross section of the vessel is not necessarily round.

iv- The cross sectional diameter may change between systole and diastole.

The overall errors in flow calculations may reach 30% in obstetric practice. The errors in A/B ratio increases as the index value increase whereas the converse holds for PI and RI ***(Nakai and Oya , 2002)***.

Although no significant difference has been observed in the value of the above Doppler indices in clinical practice, it is preferred to use RI index. PI requires digitizing the entire waveform, making it less convenient ***(Gong et al., 2005)***.

Transvaginal Doppler of the endometrium

To evaluate the endometrium by Transvaginal Doppler, we evaluate the blood flow in the uterine arteries as an indicative parameter of endometrial status.

It is confirmed that the uterine artery impedance changes occur throughout the menstrual cycle with variation in the blood flow being associated with growth of the dominant follicle and its consequent fluctuation in serum levels of estradiol and progesterone ***(Ojha et al., 2003).***

Velocity range:

Selection of velocity range depends upon whether arteries or veins are being interrogated. Arterial flow within the uterine and ovarian arteries is usually within the range of 10-50 cm s-1 peak systolic velocity, although this may be lower, particularly in postmenopausal ovarian vessels. Flow velocity in pelvic veins is in the region of 1-10cm s-1

velocity range settings should be chosen to reflect these predicted velocities **.**

❖ **Ultrasonographic anatomy of the uterine and ovarian vessels:**

- **Uterine artery:**

Uterine artery arises from the anterior division of the internal iliac artery and after it courses towards the cervix, it parts into an ascending uterine branch and a descending vaginal branch. The ascending branch courses along the side of the uterus through the outer myometrium giving arcuate branches which course in a concentric pattern within the outer 1/3 of the myometrium. For Doppler studies, the ascending branch of the uterine artery is studied where it is located in the parametrial region at the level of the internal cervical os ***(Valentin et al., 2001)***.

The ascending uterine artery can be visualized by real time Ultrasonographic as a hypoechoic area in the parametrium at the level of the internal os through lateral displacement of the vaginal probe towards the lateral fornix after identification of the internal os ***(Englert-Golon et al., 2006)***.

After switching to duplex mode, the angle of insonation is adjusted so that it crosses the long axis and the vessel at as small an angle as possible, then the sample volume is adjusted to cover the entire cross sectional area of the artery. A high pass filter is used to eliminate low frequency signals (100-200 Hz) originating from movements of the vessel walls. Once good quality signals are obtained based on audio recognition, visual waveform recognition and maximum measured velocity, the image including at least three waveform signals is freezed & various measures can now be calculated ***(Englert-Golon et al., 2006)***.

- **Ovarian artery:**

The ovarian artery originates from the aorta and reaches the ovaries via the infundibulopelvic ligament. This is the natural location to search for when Doppler studies performed. Flow velocity signals can also be elicited from the ovary itself, where a marked decrease in impedance is observed. The ovarian artery forms anastomosis with distal branches of the uterine artery, just medial to the ovary on the inferior border of the fallopian tube. It is best to perform Doppler measurements in the main artery in the infundibulopelvic ligament ***(Dal et al., 2005)***.

The technique of Doppler measurement is similar to that of uterine artery. Care should be taken not to sample the nearly internal iliac artery which is located near the lateral ovarian edge. Fortunately, the flow velocity signals from the latter vessels are generally different from those originating from the ovarian artery ***(Dal et al., 2005)***.

❖ **Transvaginal Doppler of normal endometrium in postmenopausal women**

As there is no menstrual cycle after menopause, successive changes in blood flow to the uterus are generally not demonstrated.

However, some similarities between pre- and post- menopausal women may be present. ***Kurjak and Zalud***, ***(1990)*** compared the Resistive Index values of the uterine arteries in pre- and post-menopausal women. The RI was noted to be higher in the post-menopausal patients, but apparently not statistically different. Diastolic flow was demonstrated in all subjects ***(Kurjak and Zalud, 1990)***.

The uterine arteries normally show a low velocity, high impedance pattern that increases slightly with age. Estrogen therapy may reduce the

impedance of uterine arteries in postmenopausal women and this effect is partially reversed with the addition of progesterone ***(Järvelä et al., 2001).***

❖ **Transvaginal Ultrasonography in postmenopausal bleeding**

Several sonographic studies of the endometrium which were correlated with the histopathological diagnosis had been carried out.

The endometrial echogenicity is likely to be due to the presence of glands and mucin, the frequently hypoechoic halo might possibly be related to a network of capillaries and veins around the muscle fibers in the inner layer of the myometrium. In endometrial adenocarcinoma mucin production has been found to be proportional to the differentiation of the growth. The endometrium of the normal atrophic uterus is measuring 2-3 mm by sonography and might be abnormal when measured thicker than 5 mm in postmenopausal women who are not receiving estrogen replacement therapy *(**Wolman et al., 1996**)*.

Endometrial hyperplasia appears by transvaginal sonography as well defined thickened, highly reflective layer occupying the whole endometrial cavity and surrounding by a symmetrical poorly reflective zone ***(Starczewski et al., 2005**)*.

The ability of transvaginal sonography to diagnose different types of endometrial hyperplasia have been studied by comparing different ultrasonographic pictures of endometrium including its thickness, echogenicity, borders and its homogenesity. In spite the high diagnostic accuracy of transvaginal sonography in the diagnosis of endometrial hyperplasia yet, it was not accurate in the evaluation of subtypes of endometrial hyperplasia with poor sensitivity and high false positive and negative rates ***(Momtaz et al., 2000).***

An endometrial thickness more than 8-10 mm carries an increased risk of endometrial hyperplasia. Women on long cycle hormone replacement therapy whose endometrial thickness exceeds 10 mm had 30% likelihood of associated endometrial hyperplasia ***(Ettinger et al., 1994).***

Endometrial polypi identified with transvaginal sonography by the presence of a well defined thickness of the endometrium with increased reflectivity which is surrounded by a symmetrical area of low amplitude echoes ***(Ettinger et al., 1997).***

Endocervical polypi appear as localized thickening of the endometrium close to the internal os, but in a transverse plane, the cervical canal is dilated and contains a mixed echogenic structure ***(Antunes et al., 2007).***

❖ **Transvaginal Doppler in postmenopausal bleeding:**

Uterine artery perfusion is increased owing to an elevated level of estrogens as in cases of estrogen-secreting tumors causing endometrial hyperplasia or malignancy, ovarian hyperstimulation syndrome and in benign uterine fibroids ***(Ivanov et al., 2004)***.

The value of Doppler and color Doppler U/S in distinguishing benign from malignant endometrial disease is controversial. It has been suggested that low-impedance blood flow at Doppler U/S can be associated with malignancy ***(Sawicki et al., 2005).***

Increased focal vascularity may be seen at color Doppler U/S in both benign and malignant diseases of the endometrium. Significant overlap in Doppler indices (i.e. peak systolic velocity, resistive index, pulsatility index) in benign and malignant endometrial processes reduces the value

of Doppler U/S in characterizing endometrial masses ***(Nalaboff et al., 2001).***

The vascularization of benign uterine masses is largely dependent on tumor size, position and the extent of secondary degeneration ***(Testa et al., 2002)***.

Large and laterally positioned leiomyomas, especially those with necrosis and inflammatory changes, may show increased diastolic flow and, consequently, low RI. Newly formed vessels in endometrial carcinoma can be classed as intratumoral or peritumoral. Extensive flow at the periphery of the tumor is commonly present in patients with an interrupted subendometrial halo and myometrial invasion ***(Sawicki et al., 2005).***

Direct extension to adjacent structures can be precisely assessed by analysis of the abundant flow within the myometrial portion of the uterus. Other types of spread (transtubal, lymphatic and hematogenous) cannot be assessed and analyzed by color Doppler imaging ***(Sawicki et al., 2005).***

Color and power Doppler U/S may occasionally aid in determining the presence and extent of tumor invasion and ensuring that biopsies are directed toward regions with increased blood flow ***(Fleischer, 1999)***.

In general, hyperplastic endometria do not have increased spiral arteriole vascularity which is seen in most endometrial cancers, so there is no change in pulsatility and the pulsatility index remains over 1.

Color Doppler U/S may be used to image vessels within the stalk of endometrial polyp ***(Nalaboff et al., 2001).***

Another possible application of color and pulsed Doppler is the in vivo recognition of uterine sarcoma. This tumor is rare and characterized by extremely aggressive behavior which leads to an early pattern of widespread dissemination ***(Sawicki et al., 2005).***

Doppler is used to assess blood flow in the uterine artery and the intratumoral neovascularization. The typical finding of sarcoma is irregular, thin and randomly dispersed vessels in the peripheral and/or the central area of the tumor with very low impedance shunts and low resistance in the uterine arteries ***(Sawicki et al., 2005).***

Finally, transvaginal ultrasonography with the "power" angio Doppler is a valuable diagnostic method in cases of early endometrial pathologies. The measurement of blood flow indices in endometrial vessels and uterine arteries is useful to differentiate benign and malignant endometrial pathologies. ***(Englert-Golon et al., 2006)***

However, the noninvasive methods for endometrial evaluation are not sensitive enough to exclude endometrial pathology. When invasive methods could not be performed, the combination of transvaginal sonography and power Doppler imaging provided the best results.

When both modalities are negative, the probability of cancer is less than 5% ***(Amit et al., 2000)***.

We will illustrate the sonographic appearance of most common causes of postmenopausal bleeding:

I) Endometrial causes:

A) Endometrial Carcinoma:

The most common appearance of endometrial cancer at transvaginal US is nonspecific thickening of the endometrium.

Even at sonohysterography, endometrial cancer can be difficult to distinguish from endometrial hyperplasia and polyps. This diagnosis should be suspected when the single layer of the endometrium is thicker than 8 mm, irregular, broad based, or poorly marginated or when the endometrial-myometrial interface is disrupted. Endometrial thickness measurements often overlap in benign and malignant conditions However, it has been shown that a single-layer endometrial thickness less than 2.5 mm is rarely associated with malignancy ***(Davis et al., 2002).***

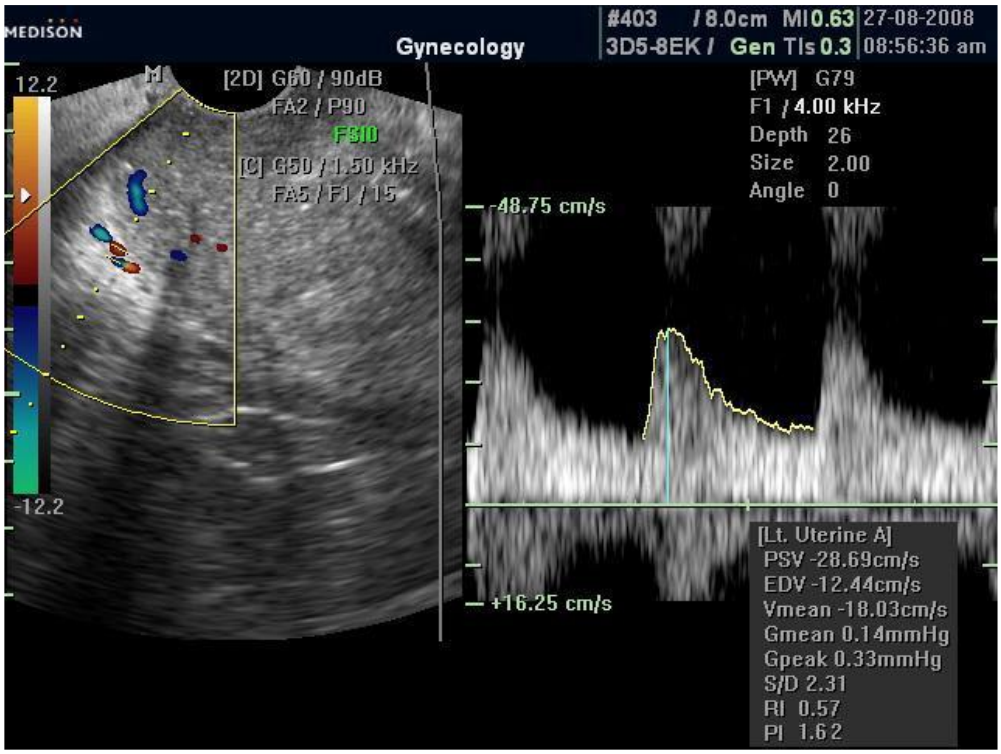

Fig. 2: Doppler parameters of the Lt. uterine artery in endometrial carcinoma *(RI 0.57, PI 1.62)* ***(Alcazar et al., 2003)***

❖ Endometrial Volume as predictor of malignancy in women with postmenopausal bleeding:-

Uterine cancer is the most common malignant neoplasm of the female genital tract and the fourth most common cancer in women. It was reported that 6000 women died of the disease in the United States in

1997, and an annual incidence of 19.5 cases per 100,000 women was recorded in Canada in 1993. Postmenopausal bleeding with endometrial atypia carries a risk of progression to cancer, but the risk of atrophic endometritis developing into cancer is minimal ***(Mansour ET AL., 2007).***

Endometrial thickness has been used as an indicator of risk for endometrial carcinoma in asymptomatic menopausal and postmenopausal women. In 2-dimensional (2D) ultrasound, the thickest anteroposterior diameter of the endometrium is measured using the 2 endometrial layers, and a cutoff value of 4 to 5 mm has been found to be predictive of pathologic changes ***(Sheikh et al., 2000).*** However, the same thickness does not express the same endometrial volume in different endometria because uterine lengths may be different and endometrial irregularities may exist.

B) Endometrial atrophy:

On ultrasound, the endometrium is less than 5 mm thick and endometrial biopsy usually yields only scant tissue **(Fig 3)** ***(Tsikouras et al., 2007).***

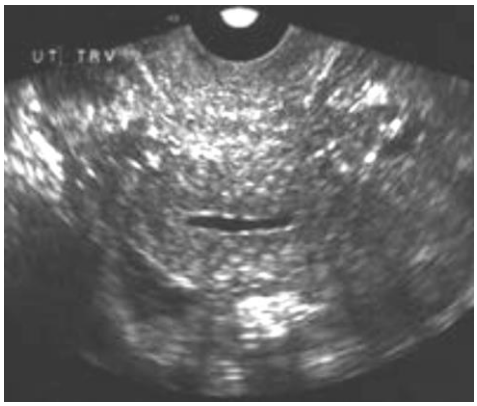

Fig. 3: Postmenopausal endometrial atrophy.

Transvaginal US image demonstrates a postmenopausal endometrium with thin walls and outlined with fluid ***(Nalaboff et al., 2001).***

B) Endometrial Hyperplasia:

Up to one-third of endometrial carcinoma is believed to be preceded by hyperplasia. All types of endometrial hyperplasia (cystic, adenomatous, atypical) can cause diffusely smooth or, less commonly, focal hyperechoic endometrial thickening ***(Nalaboff et al., 2001).***

The US appearance can simulate that of normal thickening during the secretory phase, sessile polyps, submucosal fibroids, cancer, and adherent blood clots, yielding potentially false-positive results ***(Nalaboff et al., 2001).***

Endometrial hyperplasia is considered whenever the endometrium appears to exceed 10 mm in thickness, especially in menopausal patients, although it can be reliably excluded in these patients only when the endometrium measures less than 6 mm ***(Mansour et al., 2007).***

Endometrial hyperplasia may also cause asymmetric thickening with surface irregularity, an appearance that is suspicious for carcinoma. Because endometrial hyperplasia has a nonspecific appearance, any focal abnormality should lead to biopsy if there is clinical suspicion for malignancy. (fig. 4) ***(Nalaboff et al., 2001).***

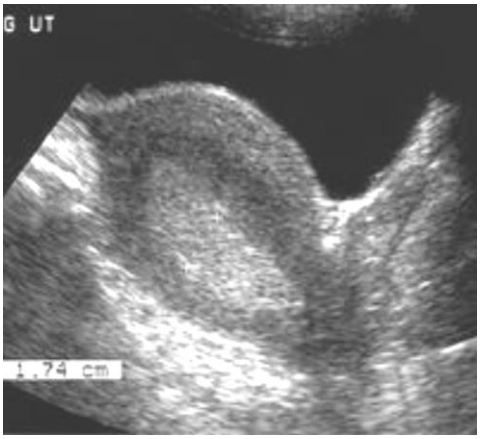

Fig.4: Endometrial hyperplasia.

US image shows an endometrium with diffuse thickening (maximum thickness, 1.74 cm) due to hyperplasia (cursors) This finding was confirmed at biopsy ***(Nalaboff et al., 2001).***

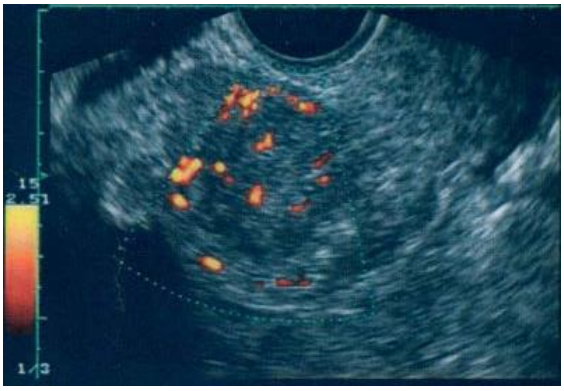

Fig. 5: Power Doppler ultrasound image showing a scattered vessel pattern characteristic of endometrial hyperplasia ***(Alcazar et al., 2003)***

D) Endometrial polyps:

The typical appearance of an endometrial polyp at sonohysterography is a well-defined, homogeneous, polypoid lesion that is isoechoic to the endometrium with preservation of the endometrial-myometrial interface. There usually is a well-defined vascular pedicle within the stalk. In contrast to the transvaginal US demonstration of polyps, which may distort measurements of endometrial thickness if

made before saline infusion, at sonohysterography the uninvolved single-layer endometrium appears normal in thickness and should be measured separately from the polyp ***(Davis et al., 2002)***.

Some of the atypical features of polyps include cystic components, multiplicity, a broad base, and hypoechogenicity or heterogeneity Occasionally, polyps can have a heterogeneous echotexture with multiple cysts. This complex appearance may indicate hemorrhage, infarction, or inflammation within the polyp. A small percentage of endometrial polyps may contain malignant foci or foci of endometrial hyperplasia ***(Davis et al., 2002).***

Cystic spaces corresponding to dilated glands filled with proteinaceous fluid may be seen within the polyp. The polyp may be broad-based and sessile or pedunculated. The point of attachment should not disrupt the endometrial lining ***(Nalaboff et al., 2001).***

Color Doppler US may be used to image vessels within the stalk.

Fibroids or foci of endometrial hyperplasia or carcinoma can mimic a sessile polyp, and foci of atypical hyperplasia are sometimes found within polyps ***(Nalaboff et al., 2001).***

E) Fibroids:

Sonohysterography allows fibroids to be classified easily and accurately by location, size, and degree of intramural extension. The major advantage of sonohysterography over other imaging modalities is that it can accurately depict the percentage of the fibroid that projects into the endometrial cavity. This feature is important because only those fibroids in which at least 50% of the mass projects into the endometrial cavity may be removed hystroscopically ***(Davis et al., 2002).***

References

Alcazar, J.L., Castillo, G., Minguez, J.A. and Galan, M.J. (2003). Endometrial blood flow mapping using transvaginal power Doppler sonography in women with postmenopausal bleeding and thickened endometrium. Ultrasound Obstet Gynecol, 21(6):583-588.

Amit, A., Weiner, Z., Ganem, N., Kerner, H., Edwards, C.l., Kaplan, A. and Beck, D. (2000). The diagnostic value of power Doppler measurements in the endometrium of women with postmenopausal bleeding. Gynecol Oncol, 77(2):243.

Antunes, A. Jr., Costa-paiva, L., Arthuso, M., Costa, J.V. and Pinto-Neto, A.M. (2007). Endometrial polyps in pre- and postmenopausal women: factors associated with malignancy. Maturitas, 57(4):415-421.

Azran, A., Hirao, Y., kinouchi, Y., Yamaguchi, H. and Yoshizaki, K. (2004). Variations of the maximum blood flow velocity in carotid, brachial and femoral arteries in a passive postural changes by a Doppler ultrasound method. Conf Proc IEEE Eng Med Biol Soc, 5:3708-37011.

Ben-Arie, A., Goldchmit, C., Laviv, Y., Levy, R., Caspi, B., Huszar, M., Dgani, R., Hagay, Z.(2004) The malignant potential of endometrial polys, Eur J Obstet Gynecol Reprod Biol , Aug 10;115(2):206-10.

Davis, P.C., O'Neill, M.J., Yoder, I.C., Lee, S.I. and Mueller, P.R. (2002). Sonohysterographic findings of endometrial & subendometrial conditions. Radiographics, 22(4):803-816.

Dal, J., vural, B., Caliiskan, E., Ozkan, S. and Yucesoy, I. (2005). power Doppler ultrasound studies of ovarian, uterine, and endometrial blood flow in regularily menstruating women with respect to luteal phase defects. Fertile sterile, 84(1):224-227.

Englert-Golon, M., Szpurek, D., Moszynski, R., Pawlak, M. and Sajdak, S. (2006). Clinical value of measurement of blood flow in uterine arteries and endometrial vessels in women with postmenopausal bleeding using power angio Doppler technique. Ginekol pol, 77(10):759-763.

Ettinger, B., Bainton, L., Citron, J.T. and Upmalis, D.H. (1997). Comparison of endometrial growth produced by unopposed conjugated estrogens or by micronized oesradiol in postmenopausal women. Am Obstet Gynecol, 176:122-117.

Ettinger, B., Selby, J., Citron, J.T. and Van, Gessel. (1994). Cyclic hormone replacement therapy using quarterly progestin. Obstet. Gynecol, 83:643-670.

Gong, X., Li, Q. Zhang, Q. and Zhu, G. (2005). Predicting endometrium receptivity wiyh parameters of spiral artery blood flow. J Huazhong Univ Sci Technolog Med Sci, 25(3):335-338.

Ivanov, S., Katerinski, K., and Zervoudis S. (2004). Study of neovascularization in endometrial cancer and hyperplasia

using angio-doppler technique. Akush Ginekol (Sofiia), 43(2);41-43.

Järvelä, I., Tekay, A., Santala, M., and Jouppila, P. (2001). Thermal ballon endometrial ablation therapy induces a rise in uterine blood flow impedence: a randomized prospective color Doppler study. Ultrasound Obstet Gynecol, 17(1):65-70.

Kurjak, A. and Zalud, I. (1990). Transvaginal color Doppler in the study of uterine perfusion. In: Mashiach, S., Ben-Rafael, Z., Laufer, N. and Scheneker, J.G. Advances in Assisted Reproductive technologies. New York: Plenum Press; 541.

Mansour, G.M., El-Lamie, I.K., El-Kady, M.A., El-Mekkawi, S.F., Laban, M. and Abou-Gabal, A.I. (2007). Endometrial volume as predictor of malignancy in women with postmenopausal bleeding. Int J Gynaecol Obstet, 99(3):206-610.

McMichael, R.D. and Stiles, M.D. (2008). Physics. A new spin on the Doppler effect. Science, 322(5900):386-387.

McParland, P.J. and Pearce, J.M. (1990). Uteroplacental and fetal blood flow. In: Chamberlain, G. (ed). Modern Antenatal Care of the fetus, Chapter 6:89.

Momtaz, M., Khalil, A., Al Balkini, N., El Shenoofy, O. and Mosaad, M. (1993). Transvaginal sonographic characterization of endometrial hyperplasia. J Egyptian Soc Obstet Gynecol, (1):43.

Nagai, Y. and Hayashi, N. (2008). Karmer-Pesch approximation for analuzing field-angle-resolved measurments made in

unconventional superconductors: a calculation of the zero-energy density of states. Phys Rev Lett, 101(9):097001.

Nalaboff, K.M., Pellerito, J.S. and Ben-Levi, E. (**2001).** Imaging the Endometrium: Disease and Normal Variants. Radiographics, 21:1409.

Oddershede, N., Gran, F. and Jensen, J.A. (2008). Multi-frequency encoding for fast color flow or quadroplex imagibg. IEEE Trans Ultrason Ferroelectr Freq Control, 55(4):778-786.

Ojha, K., Sladkeviciuss, P., Scaramuzzi, R., Collier, T., Campbell, S. and Nargund, G. (2003). Side of ovulation and its effects on uterine and ovarian stromal blood flow and reproductive hormones. Fertil Steril, 79(2)**:**367.

Rubin, J.M., Adler, R.S. and Fowlkes, J.B. (1995). Fractional moving blood volume estimation using power Doppler US. Radiology, 197:183.

Sawicki, V., Spiewankiewicz, B., Stelmachow, J.K. and Cendrowski, K. (2005). Color Doppler assessement of blood flow in endometrial cancer. Eur J Gynaecol Oncol, 26(3):279-284.

Sheikh, M., Sawhney, S., Khurana, A. and Al-Yatama, M. (2000). Alteration of sonographic texture of the endometrium in post-menopausal bleeding. A guide for further management. Acta Obstet Gynecol Scand, 79(11):1006-1010.

Starczewski, A., Brodowska, A., Strjny, K., Puchalski, A., Mieczkowska, E. and Szydlowska, I. (2005). The value of ultrasonography in diagnosis of atypical endometrial

hyperplasia in postmenopausal women. Przegl Lek, 62(4):227-229.

Tsikouras, P., Galazios, G., Liberis, V., Bouzaki, A., Grapsas, X. and Maroulis, G. (2007). TV sonographic assessement in postmenopausal asymptomatic women. Eur J Gynaecol Oncol, 28(6):473-476.

Valentin, L., Sladkevicius, P. and Bland, M. (2001). Intraobserver reproducibility of Doppler measurments of uterine artery blood flow velocity in premenopausal women. Ultrasound Obstet Gynecol, 17(5):431-433.

Wolman, I., Sagi, J., Giant, S. and Jaffa, A.J. (1996). Sensitivity and specificity of vaginal sonography in detecting endometrial abnormalities in women wiyh postmenopausal bleeding. J Clinic Ultrasound, 24(2)79-82.

Yoo, Y.M., Managuli, R. and Kim, Y. (2007). New multi-volume rendering technique for 3D power Doppler imaging. Ultrasonic, 46:313-322.

Zhang, Z., Jakobsson, A., Macleod, M. and Chambers, J. (2005). On the efficient estimation of blood velocities. Conf oroc IEEE Eng Med Biol Soc, 7:7421-424.