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● *Original Contribution*

CHARACTERIZATION OF PELVIC ORGANS BY DOPPLER SONOGRAPHY WAVEFORM SHAPE

TEPPER RONNIE,* SHAHARABANY YODFAT,† SHIRI RON,* and RELI HERSHKOVITZ‡

*Department of Obstetrics and Gynecology, Ultrasound Unit, Meir University Medical Center, Kfar-Saba, Israel; †Abramson Center for Medical Physics, Tel-Aviv University, Tel Aviv; and ‡Department of Obstetrics and Gynecology, Soroka University Medical Center, Ben Gurion University of the Negev, Beer-Sheva, Israel

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Abstract—The purpose was to describe blood flow waveform of pelvic organs obtained by Doppler according to their unique characteristics. A prospective study was designed and 79 premenopausal and postmenopausal women were screened. Transvaginal ultrasonography combined with color Doppler was performed. Arterial blood flow of the uterus, fallopian tubes and both ovarian center and periphery were assessed, by a unique computerized program exclusively developed for this research (MATLAB language). Waveform characterization was performed by calculating α and β angles, representing upward curve of each waveform and angles of refraction γ and δ. α to δ angles were found significantly different for each of the pelvic organs. Significant differences in the characteristics of Doppler waveforms were also observed between pre and postmenopausal women. Luteal and follicular phase blood flow waveforms were similar. These findings contribute to our ability to classify the origin of blood vessel by processing Doppler waveforms by a computerized method. (E-mail: ralikah@bgumail.bgu.ac.il) © 2010 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Color Doppler flow, Pelvic organs, Computerized waveform analysis.**

INTRODUCTION

Doppler blood flow velocimetry is considered a useful tool in the sonographic gynecologic evaluation of the vasculature of various tissues and organs (Schiller and Grant 1992). The blood flow waveform is influenced by a few factors. Type of blood vessel; *i.e.,* artery, vein or capillary, and hormonal variations are some of these factors (Schiller and Grant 1992). The consequence of the hormonal changes is different angiogenesis at different stages of the menstrual cycle. The ovaries and uterus are the main organs influenced by these hormonal changes (Dill-Macky et al. 2000; Fleischer et al. 1993, 1996).

One of the challenges of the sonographers is the diagnosis of the origin and the nature of various tumors in the pelvis. Based on sonographic appearance only, differentiating between ovarian, uterine or tubal origin of tumors may not always be simple. Adding Doppler blood flow velocimetry may be helpful (Dill-Macky and Atri 2000; Fleischer et al. 1993, 1996).

Doppler blood flow pattern is known to be different between different organs, especially between the ovaries and the uterus (Dill-Macky and Atri 2000; Fleischer et al. 1993, 1996). However, in cases of adjacent enlarged organs using Doppler studies, may not point accurately to the origin of tumor, benign or malignant.

One of the explanations for the poor performance of the Doppler sonography may be the use of the known Doppler parameters. These parameters utilize the relation between the systolic and the diastolic flow velocity quantifiable by the pulsatility index (PI), resistance index (RI) and S/D ratio (Dill-Macky and Atri 2000; Fleischer et al. 1993, 1996; Shaharabani et al. 2004). Those parameters disregard the specific patterns of the blood vessels of the different pelvic organs. The purpose was to describe blood flow waveform of pelvic organs obtained by Doppler according to their unique characteristics.

MATERIALS AND METHODS

Population

A prospective study was designed and healthy women, both in the reproductive and postmenopausal age were enrolled. Exclusion criteria were patients with

Address correspondence to: Reli Hershkovitz, M.D., Ultrasound Unit, Department of Obstetrics and Gynecology, Soroka University Medical Center, P.O.B. 151, Beer–Sheva 84101, Israel. E-mail: ralikah@bgumail.bgu.ac.il

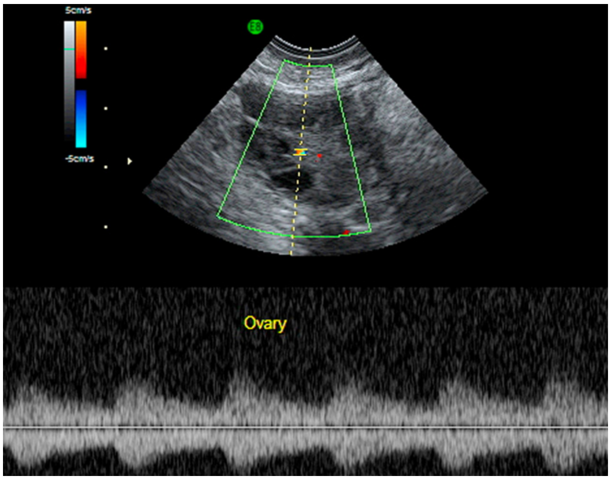

Fig. 1. Doppler blood flow velocimetry of the ovary - central area.

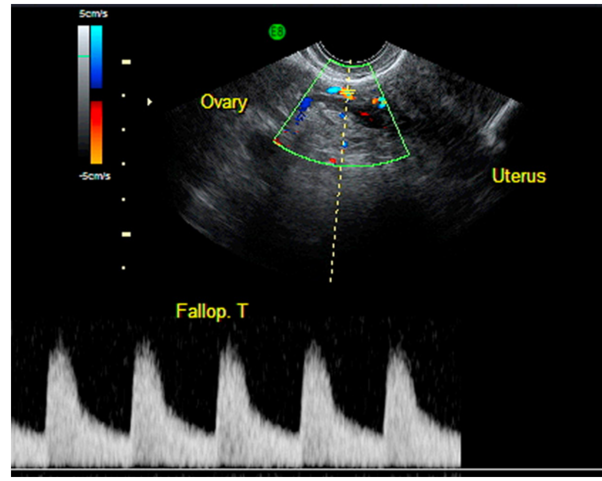

Fig. 3. Doppler blood flow velocimetry of the fallopian tube.

pelvic pathology as proven by ultrasound, patients with oral contraceptive or hormonal replacement therapy and pregnant women. The local Institutional Review Board approved the study and patients gave their consent.

Ultrasound examination

Sonographic examination was performed with a 5 to 9 MHz vaginal probe of HDI 5000 ultrasound device (Philips, Seattle, WA, USA). Every woman underwent a transvaginal sonographic examination combined with color and pulse Doppler. Arterial blood flow was assessed in the center and periphery of the ovary, fallopian tubes and in the uterus (Figs. 1–4).

Computerized data processing

Doppler waves were directly transferred to the computer for processing. One image, containing a sequence of waves, was taken for each anatomical site (*i.e.*, ovary, uterus and fallopian tubes). The visual process

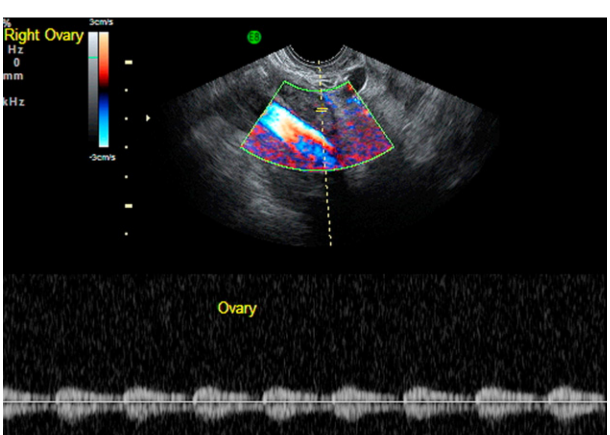

Fig. 2. Doppler blood flow velocimetry of the ovary: peripheral area.

of the data was performed with a special program developed for this study and written in MATLAB 6.0 language. This program receives the input data as a Doppler image of the blood flow in the different sites (*i.e.*, ovary, uterus and fallopian tubes), containing 512 pixels × 512 pixels × 256 gray levels. Thus, the data was composed of time axis, velocity axis and gray levels, which are proportional to the number of the red blood cells flowing through the blood vessel. All calculations were performed on the curve derived from the maximum spectral velocity, the waveform curve. To perform the waveform delimitation, the Doppler flow image was smoothed by a median filter with a window size of 11 × 11 pixels and the waveform contour was automatically extracted by threshold. In addition, each wave in the image was isolated to carry out a linear fit to different parts of its waveform curve.

In this study the spectral temporal axis did not change among the images, neither did the Doppler scale in most of the images (*i.e.*, most of the images were taken at PRF 1515, while the others were normalized according to this formula):

$$\Delta\theta = \arctan\left[\frac{(1-k)\cdot m}{k+m^2}\right]$$

While θ = the measured angle, $m = \tan(\theta)$, k is the scales ratio, *i.e.*, $k = \frac{1515}{PRFvalue}$ and $\theta\Delta$ is the correction that was added to the measured angel in images with PRF other than 1515.

User who measures an angle by setting a different spectral vertical scale (*i.e.*, any PRF other than 1515), can compare it to our table of angle values by simply using the above formula.

The following four angles were calculated using these linear fits:

(1) Alpha (α) angle was measured when considering only the part of the wave between the end-diastole and the

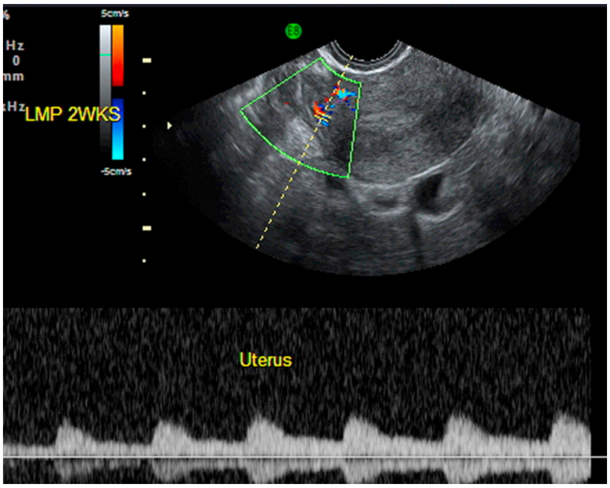

Fig. 4. Doppler blood flow velocimetry of the uterine artery.

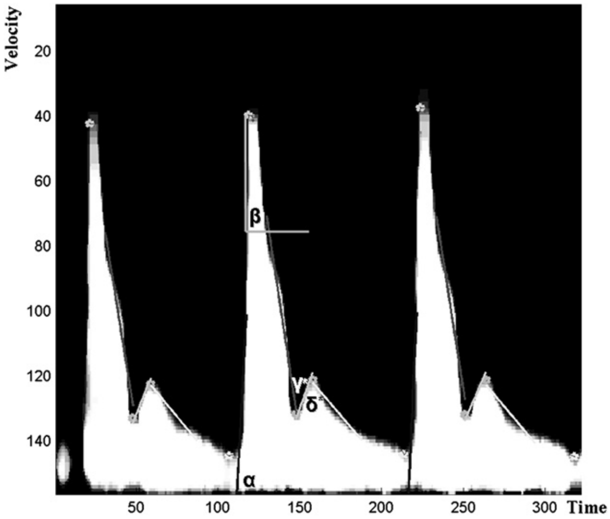

Fig. 5. Doppler waveform: angles of measurement are presented: α angle: the angle of the wave between the time axis X and the linear fit. β angle: the angle of the wave between the time axis X and the straight line that connects 2 points on the curve. γ and δ: angles of refraction.

systolic peak. The angle between the time axis X and the linear fit (straight line) matched to the curve between the previous diastole and the following systolic peak (Fig. 5). To enhance the accuracy and avoid deformity of the linear fit due to the round shape of the curve immediately after end-diastole and before the systolic peak, we discarded 15% and 40% from the leftmost and the rightmost of the curve, respectively.

(2) Beta (β) angle: The angle between the time axis X and the straight line that connects two points on the curve (Fig. 5). The first point represents a distance of 66% of the curve length following the end-diastole, while the second is located at the following systolic peak.

(3) Considering the part of the wave between the systolic peak to the end-diastole gamma (γ) angle was calculated. This is the first angle of refraction. This angle is formed by the intersection of the straight lines matched with the curve between the systolic peak to the second diastolic change (Fig. 5). The first line is a linear fit performed for the rightmost 60% portions of the curve between the systolic peak and the first tendency of modification during the diastolic phase. The second line is a linear fit performed for the waveform curve between that point and the second tendency modification during the diastolic phase.

(4) Delta (δ) angle: This is the second angle of refraction during the diastolic phase. This angle is formed by the crossing of the straight lines matched with the curve, between the first diastolic change to the end diastole (Fig. 5)

Statistical analysis

Statistical analysis was performed by the SPSS package (SPSS, Chicago, IL, USA). Mean and standard deviation (SD) was calculated. The mean differences in the waveform parameters of the different organs were calculated for each age group. For calculating differences between the groups *t* test was used.

RESULTS

Seventy-nine women were recruited. Two different groups were studied: 41 reproductive/premenopausal age women with an average age of 34.2 years (range 22–52 years) and 38 postmenopausal women (at least 1 year after amenorrhea) with an average age of 58.3 years (range 51–74 years). Two women with spontaneous regular cycles aged 52 years were included in the fertile group. Six additional women were included in the study but unfortunately

Table 1. Waveform parameter angles of pelvic organs in both groups

	Fallopian tube (Mean ± SD) (°)	Uterus (Mean ± SD) (°)	Ovarian center (Mean ± SD) (°)	Ovarian periphery (Mean ± SD) (°)
α	77.8 ± 8.2	86.2 ± 1.7	66.9 ± 13.4	53.9 ± 13.2
β	71.8 ± 12.8	81.7 ± 3.8	52.3 ± 12.3	41.0 ± 11.4
γ	110.7 ± 23.8	90.4 ± 19.6	138.8 ± 11.5	149.1 ± 10.0
δ	151.3 ± 22.8	134.9 ± 20.5	164.2 ± 11.8	167.5 ± 7.5

$p < 0.05$ statistically significant.
NS = nonsignificant.

Table 2. Waveform parameters with significant statistical differences between organs in reproductive age group

	Ovarian periphery	Ovarian center	Fallopian tube	Uterus
Uterus	α, β, γ, δ	α, β, γ, δ	α, β, γ, δ	—
Fallopian tube	α, β, γ, δ	α, β, γ	—	α, β, γ, δ
Ovarian center	α, β, γ	—	α, β, γ	α, β, γ, δ
Ovarian periphery	—	α, β, γ	α, β, γ, δ	α, β, γ, δ

$p < 0.05$ statistically significant.
NS = nonsignificant.

examination was discontinued (two patients due to tenderness, and in another four patients, due to the position of the uterus, obesity and uterine distortion by myomas).

The easiest waveforms to obtain were the waveforms from the uterine arteries (99.6% of the total collected waves) and the rarest were from the ovarian periphery in the postmenopausal group (10.4% of the waveforms collected in the postmenopausal group).

Table 1 presents the different waveform parameters at the different organs. Tables 2 and 3 present the statistical differences between the different organs at the reproductive age (Table 2) and at the postmenopausal patients (Table 3). In Table 3, no statistical differences were noted between in any angles between these two organs in the postmenopausal group. Therefore, it remained blank. The values of the alpha (α) and beta (β) angles in the uterine artery (Table 1) are greater than in the other organs and demonstrate the fast development of flow, up to the systolic peak. Gamma (γ) and delta (δ) angles (Table 1) were found smaller in the uterine artery compared with the other organs, showing the presence of a diastolic notch of the uterus waveform.

Tables 4–7 present the waveform parameters for each organ, in both study groups, including the number of waves tested, the mean size of the angle and the standard deviation. All uterine artery waveforms were found to be significantly different between both study groups (Table 4). Tubal β, γ, δ waveform parameters were significantly different between both groups (Table 5). α, β, γ waveform parameters at the ovarian center were different between both groups (Table 6). Waveform parameters at the ovarian periphery in the

Table 3. Waveform parameters with significant statistical differences between the different organs in postmenopausal age group

	Ovarian periphery	Ovarian center	Fallopian tube	Uterus
Uterus	α, β,	α, β, γ,	α, β,	—
Fallopian tube		α, γ,	—	α, β,
Ovarian center	δ	—	α, γ,	α, β, γ,
Ovarian periphery	—	δ		α, β,

$p < 0.05$ statistically significant.
NS = nonsignificant.

reproductive and postmenopausal age groups were similar (Table 7).

Summary of the differences between the pre and postmenopausal women in the different arteries is presented in Table 8. Blood flow in the uterine artery, ovarian center and fallopian tubes are different in most of the angles. No significant changes were observed in the blood flow angles in the ovarian periphery.

A significant statistical difference was found between the number of the peripheral ovarian waves obtained from the postmenopausal women (28 waves) and those of the fertile group (65 waves).

In the reproductive age group, two subgroups were further analyzed: women in the follicular phase - days 1 to14 of the cycle ($n = 17$) as opposed to women from the 15th day up to the first day of menstruation ($n = 24$), no significant statistical difference was found in the flow wave structure in any of the four organs in both subgroups. In the postmenopausal group, two subgroups were compared as well: women 1 to 4 years after menopause ($n = 12$) compared with women over 5 years after menopause ($n = 26$). No significant statistical difference was found in the flow wave structure in any of the four organs in both subgroups. No correlation was found between the different parameters and age, BMI or heart rate. The test was performed with Pearson correlation test.

Table 9 represents the γ angle among both groups. A flattening tendency was observed was demonstrated in the post menopausal group.

To study the inter-observer and intra-observer variance, 10 measurements for each of the four organs were conducted by the same operator in two different participants, one fertile and the other postmenopausal. No intra-operator differences regarding the values of the waveform parameters (SD is 0% to 14.43% of the mean) were significant. No significant differences between the parameters were obtained by different program operators (inter-operator) for the computer analysis (Table 10).

DISCUSSION

This study is the first study to the best of our knowledge, to describe and characterize in a systematic way the

Table 4. Uterine artery waveform parameters in the postmenopausal and the reproductive age groups

	Postmenopausal women (n = 41)		Reproductive age women (n = 38)		
	N	Mean ± SD (°)	N	Mean ± SD (°)	p
α	33	85.1 ± 22.4	33	86.2 ± 1.7	0.044
β	33	74.0 ± 7.3	34	81.7 ± 3.8	<0.0001
γ	34	12.4 ± 26.2	35	90.4 ± 19.6	<0.0001
δ	34	178.1 ± 23.3	35	134.9 ± 20.5	<0.0001

$p < 0.05$ statistically significant.
NS = nonsignificant.

Table 6. Waveform parameters in the ovarian center in the reproductive and post- menopausal age groups

	Postmenopausal women (n = 41)		Reproductive age women (n = 38)		
	n	Mean ± SD (°)	n	Mean ± SD (°)	p
α	20	51.9 ± 14.0	30	66.9 ± 13.4	<0.0001
β	20	40.5 ± 12.2	30	52.3 ± 12.3	0.002
γ	20	147.3 ± 11.4	31	138.8 ± 11.5	0.013
δ	20	159.7 ± 12.1	31	164.2 ± 11.8	NS

$p < 0.05$ statistically significant.
NS = nonsignificant.

pattern of the Doppler waveforms of blood vessels of different pelvic organs. In the current study, we have tested the differences between the structures of the blood flow waves in different pelvic organs: the uterus, fallopian tubes and ovarian center and periphery, in both fertile and postmenopausal women.

In the reproductive/premenopausal women group, significant differences were found between the values of the alpha (α), beta (β) and gamma (γ) angles between all pelvic organs. Differences were also found between the delta (δ) angles in the uterus in comparison to the other pelvic organs. In postmenopausal women, the difference between the various waveforms was evident in a smaller number of parameters but still sufficient for discerning between the various pelvic organs.

A difference was also found between the number of the peripheral ovarian waves technically obtained from the postmenopausal women and those of the fertile group. This may be due to the relatively smaller and hypovascular ovaries of postmenopausal woman as suggested before (Fleiscer et al. 1996). These differences can be helpful in assessing the pelvic organ from which the blood vessel originates in complicated cases.

The relationship between the hormonal status and the flow wave structure was already studied and described by several researchers (Steer et al. 1990; Hata et al.1990; Jale et al. 2005). In the present study, it is notable that the refraction angle gamma (γ) is smaller in fertile women compared with postmenopausal women. We have not calculated the peak systolic value or the diastolic value of the wave forms. Yet, we have found a clear tendency towards flattening of the gamma (γ) angle in fertile compared with postmenopausal participants. A statistically significant rise in the mean value of the gamma (γ) angle between the two stages (systole and diastole) was observed in the postmenopausal group. The presence of an extinguishing diastolic wave with such a sharp angle in the reproductive age group indicates the ability of the blood vessel wall to react to the passing blood volume by contraction. It can be estimated that the magnitude of this contraction is dependent on the muscular mass in the blood vessel wall. In the postmenopausal group the values of the angle gamma (γ) indicate the loss of the diastolic notch, which may be caused by the diminution of the muscular layer of the blood vessel wall.

A waveform shape is also related to the heart function, blood vessel wall structure and size, the extent of flow resistance in the target organ and the hormone status (Despot et al. 1997; Bonilla-Musoles et al. 1995; Warren 1979). Previous studies have recommended improving the differentiation of pelvic findings, benign or malignant, with the aid of values obtained from the flow wave form (Dill-Mack and Atri 2000; Fleicher et al. 1993, 1996, Steer et al. 1990; Hata et al.1990; Jale et al. 2005; Warren 1979; Hamper et al. 1993; Fisher and Llaurado 1996). It is known that the structure of the wall blood

Table 5. Tubal waveform parameters in the reproductive age and postmenopausal age groups

	Postmenopausal women (n = 41)		Reproductive age women (n = 38)		
	n	Mean ± SD (°)	n	Mean ± SD (°)	p
α	12	75.1 ± 10.7	21	77.8 ± 8.2	NS
β	12	60.5 ± 16.5	21	71.8 ± 12.8	0.036
γ	15	128.2 ± 21.5	22	110.7 ± 23.8	0.029
δ	15	168.8 ± 16.5	22	151.3 ± 22.8	0.016

$p < 0.05$ statistically significant.
NS = nonsignificant.

Table 7. Waveform parameters at the ovarian periphery in the reproductive and postmenopausal age groups

	Postmenopausal women (n = 41)		Reproductive age women (n = 38)		
	N	Mean ± SD (°)	n	Mean ± SD (°)	p
α	7	52.3 ± 20.0	34	53.9 ± 13.2	NS
β	7	36.0 ± 13.8	34	41.0 ± 11.4	NS
γ	8	152.9 ± 15.2	34	149.1 ± 10.0	NS
δ	8	167.4 ± 9.1	34	167.5 ± 7.5	NS

$p < 0.05$ statistically significant.
NS = nonsignificant.

Table 8. The differences between reproductive and postmenopausal women

	Ovarian periphery	Ovarian center	Fallopian tube	Uterus
α	NS	$p = 0.000$	NS	$p = 0.044$
B	NS	$p = 0.002$	$p = 0.036$	$p = 0.000$
Γ	NS	$p = 0.013$	$p = 0.029$	$p = 0.000$
δ	NS	NS	$p = 0.016$	$p = 0.000$

$p < 0.05$ statistically significant.
NS = nonsignificant.

vessels and the elastin:collagen ratio differs in different vessels (Hamper et al. 1993; Bourne et al. 1993; Sabbagha et al. 1994). It appears that this difference is a pivotal factor that affects the flow wave structure in the uterine and ovarian arteries.

In other studies, it was shown that changes occurred in the flow wave related to the cycle phase dependent on hormonal factors (Sabbagha et al. 1994). However, no differences between the flow wave characteristics in the luteal phase and the follicular phase were found in the present study. A possible explanation for this finding is that most of the previous studies used the flow resistance values, which are sensitive to hormonal changes, while the present study examined parameters that might be influenced more by the mass of the muscular fibers, which do not change throughout the cycle. This fact can assist in the diagnosis of the origin of the blood vessel during the whole menstrual cycle.

In addition, in the postmenopausal group, we compared the waveform parameters of two subpopulations: women during first year after menopause and 1 to 5 years after menopause. No statistically significant differences were found.

We examined a possible influence on the study results by the operator's subjective choice of the level of brightness in the computer program. An experienced sonographer usually can differentiate between the different pelvic organs. However, we believe that in certain cases, this task may be difficult and Doppler may be helpful. Also, no significant differences between the different angles were found in the present study with changing levels of brightness unimportant inter/intra-operator differences were observed. This fact also contributes to

Table 9. γ angle in the reproductive age group and postmenopausal group

	Postmenopausal group	Fertile group	
	Mean ± SD (°)	Mean ± SD (°)	p
Uterus	123.4 ± 26.2	90.4 ± 19.6	0.0001
Fallopian tube	128.3 ± 21.6	110.8 ± 23.8	0.029
Ovarian center	147.3 ± 11.4	138.8 ± 11.5	0.013

Table 10. Inter-operator differences

	Ovarian periphery	Ovarian center	Fallopian tube	Uterus
α	NS	NS	NS	NS
B	NS	NS	NS	NS
Γ	0.004	NS	0.016	NS
δ	NS	0.0001	NS	NS

$p < 0.05$ statistically significant.
NS = nonsignificant.

the accuracy of the results and especially in complicated pelvic masses. However, possible biases in the study might be due to the unpreventable fact that the examiner observes the structure of the Doppler flow wave while performing the test. Also, in the present study, neither the participant's heart rate nor her body mass affected results.

In summary, the computerized analysis of the different parameters presented in the present study can help in assessing the origin of complicated pelvic findings, assessing in evaluation of fertility and to add information when assessing the postmenopausal state. The goal is a computer aided diagnosis. Today, only the pulsatility index (PI), resistance index (RI) and systolic/diastolic (S/D ratio) indices are presented on the ultrasound screen. We hope that our results would also appear on the ultrasound screen and could be used on every day basis where needed.

In conclusion, to the best of our knowledge, this is a pioneering study in this field. We have found significant differences in most blood flow values (alpha [α], beta [β] and gamma [γ] angles) between the different pelvic organs among the premenopausal women group. In the postmenopausal women, the difference between the various waveforms was evident in a smaller number of parameters but still sufficient for discerning between the various pelvic organs. Moreover, the values of the different angles were statistically different between pre- and postmenopausal women, accept for the ovarian periphery. No significant differences were found between the luteal and follicular phases. Nevertheless, this technology should further be evaluated to establish its potential clinical application.

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