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Quantitative ultrasound diagnosis of endometrial cysts

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Summary: We measured the ultrasonic frequency dependent attenuation of ovarian cysts using the spectral difference method to find the difference in the characteristics of attenuation of the endometrial cyst and other ovarian cysts. We investigated an analytical method to measure the ultrasonic frequency dependent attenuation of ovarian cysts and we called this method the boundary echo spectrum method.

The endometrial cyst had an attenuation slope of 0.67 ± 0.27 dB/cm/MHz, and attenuation value was 1.85 ± 1.27 dB/cm, and it had significantly higher attenuation slope and attenuation value compared with those of serous cystadenoma and mucinous cystadenoma, but no significant difference compared with those of dermoid cyst (fat component).

Compared with attenuation slope and attenuation value, attenuation slope is superior because of smaller standard deviation and better linearity between water immersion and transabdominal method.

Key words: Ovarian cysts; Ultrasound.

INTRODUCTION

Endometriosis is a non-neoplastic disease of unknown etiology that occurs frequently in the myometrium, uterine adnexae and Douglas' pouch, and especially in the ovary where it forms endometrial cysts. Owing to the recent increase in endometriosis and the development of danazol therapy, the ultrasonic diagnosis of endometrial cysts has become more important. However, when using ultrasonography it is often difficult to distinguish endometrial cysts from other cystic diseases.

On the other hand, since a study concerning the ultrasonic linear frequency dependent attenuation in the liver was published by Kuc *et al.* [1], there have recently been many studies regarding diagnosis by the use of tissue characteristics. This involves the quantitative use of image information as an approach to diagnosis, by measuring various acoustic parameters of ultrasound (attenuation, acoustic speed, posterior scattering, etc.), and can be contrasted to the former method of ultrasonic diagnosis using pattern recognition on B mode images.

In this study we have collected data with respect to the frequency dependent

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attenuation, which is one of the useful parameters. In previous reports, it was possible to measure the frequency dependent attenuation in tumors and organs showing a homogeneous internal echo (2), except for tissues like cysts that show a strong boundary echo and a weak internal echo.

We investigated an analytical method for measuring the ultrasonic frequency dependent attenuation of ovarian cysts, and found clear differences in the characteristics of attenuation of endometrial cysts and other ovarian cysts.

MATERIALS AND METHODS

The ultrasonic image processing system used was an Aloka UIP-100 medical image processing system, connected to ultrasonic diagnostic equipment with a digital scan converter (Aloka SSD-190S) (Fig. 1) (3). The Aloka SSD-190S has a probe of 3.5 MHz center frequency, and is capable of collecting radio frequency (RF) signals and image data. The collection of RF signals is performed by establishing a region of interest (ROI) at an optional portion on a B-mode image. The transverse dimension of the ROI contains 64 ultrasonic beams and the longitudinal dimension is 2 cm. Since one beam contains 512 sampling points in a length of 2 cm, 32.678 RF signal points are sampled in the whole ROI. It is also possible to establish ROIs of 32 beams × 4 cm, 16 beams × 8 cm, and 8 beams × 16 cm. The collected image data and RF signals are transmitted to the ultrasonic image processing apparatus (Aloka UIP-100), and fast Fourier transformation (FFT) is used to process the raw data. Then a power spectrum and the attenuation coefficients are displayed (Fig. 2).

An investigation was made on patients who underwent oophorectomy at the Department of Obstetrics and Gynecology, Okayama University Hospital from 1985 to 1989. There were 17 patients with serous cystadenomas, 10 with mucinous cystadenomas, 21 with endometrial cysts, and 22 with dermoid cysts containing mainly fat and a very small amount of hair, but forming no hair balls. USG was performed before the operation and the simultaneous collection of radio frequency data for reflected waves was undertaken transabdominally in accordance with the method stated later. Data analysis was performed with the UIP 100 to determine the

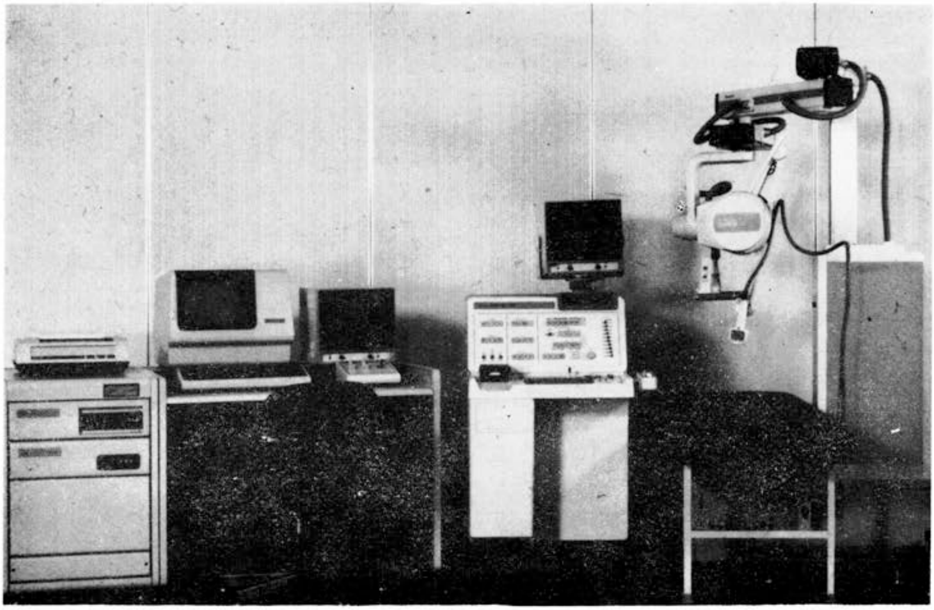


Fig. 1. — Outlook of the systems, which we used in measuring the ultrasonic attenuation coefficients.

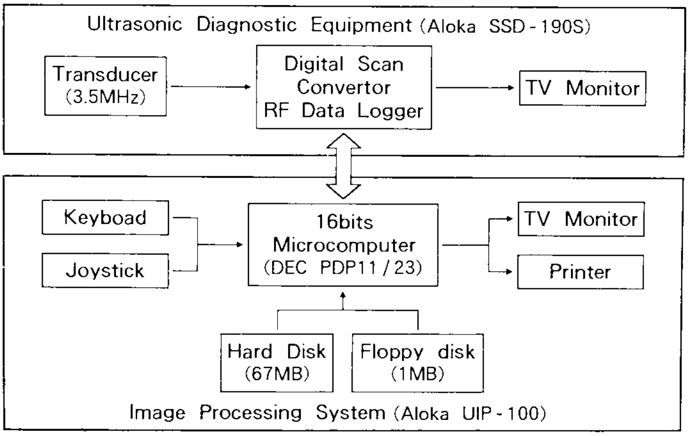


Fig. 2. — System block diagram of medical image processing system of ultrasound.

characteristics of the frequency dependent attenuation in each case (Table 1).

First ROIs were established at 2 sites having different depths on the B-mode image, namely on the anterior and posterior walls of a cyst, and radio frequency data were collected for the waves reflected from these regions (Fig. 3). Then, by subjecting the radio frequency data of the reflected wave to FFT, the power spectra were obtained, and the differences between the power spectra were calculated to obtain the characteristics of frequency dependent attenuation.

The method of calculation was as follows (4).

A model is considered that is composed of very small scattering bodies present at random in a uniform medium of attenuation coefficient α (f) and sound speed v. Here f is frequency, and it is expressed as $\alpha(f) = \alpha_0 \cdot f$. For the sake of brevity, as shown in Fig. 4, a 2-dimensional model is considered in the region of $x \geqq 0$. It is assumed that an ultrasonic pulse is disseminated as a plane wave with the beam width 2b, and

Table 1. — *Case ultrasonography and collected the frequency data performed.*

Histological type	Number of cases	
	Transabdominal method	Immersion method
Endometrial cyst	21	6
Serous cystadenoma	17	7
Mucinous cystadenoma	10	3
Dermoid cyst (fat)	22	4

that a scattered wave can also be regarded as a plane wave parallel to the surface of the oscillator.

Among the echo signals arising from the interior of the specimen, only the signal Wt_0 (t) is considered which arises from the region expressed by $t_0 \leqq t \leqq t_0 + \tau$ · this is approximated to a reflected wave from scattering bodies in $t_0 \cdot v/2 \leqq X \leqq (t_0+\tau) \cdot v/2$, and using these suppositions the approximation formula can be expressed as follows:

$$Wt_0(t) = \int_{y_0-b}^{y_0+b} \int_{t_0 v/2}^{(t_0+\tau)v/2} r(x,v) \int_{-\infty}^{\infty} S(f) \exp\{-2\alpha(f)x\} \exp\{-2\pi jf(2x/v)\} \exp\{2\pi j ft\}\, df\, dx\, dy \quad (1)$$

Here r (x, y) signifies thecoefficient of reflection at the point (x, y), and S (f) means the Fourier transformation of an ultrasonic pulse waveform.

This formula is subpected to Fourier transformation and the expected values of each power spectrum of signal Wt_0 (t) and Wt_1 (t) [taken from the parts of $t_0 \leqq t \leqq t_0+\tau$ and $t_1 \leqq t \leqq t_1+\tau$] are expressed as $\langle |Wt_0(f)|^2 \rangle$ and $\langle |Wt_1(f)|^2 \rangle$. The attenuation coefficient α (f) can be calculated by the following formula:

$$\alpha(f) = \ln(\langle |Wt_0(f)|^2 \rangle / \langle |Wt_1(f)|^2 \rangle) / \{2v(t_1 - t_0)\} \quad (2).$$

In human tissue, the attenuation coefficient α (f) is almost proportional to frequency, so that it can be written as

$$\alpha(f) = \alpha_0 \cdot f \quad (3)$$

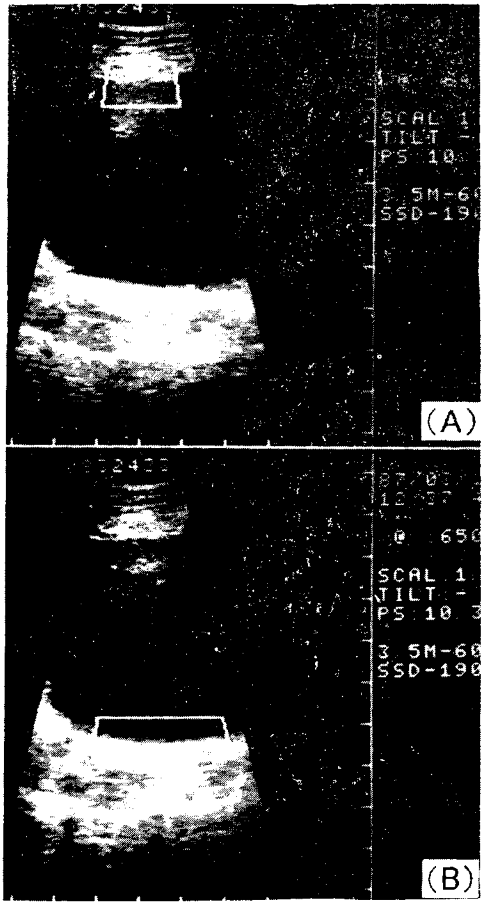


Fig. 3. — We established the ROI on the anterior wall of a cyst (A), and posterior wall of a cyst (B).

The slope of the attenuation coefficient α_0 is one of the important parameters representing frequency dependent attenuation. In this paper, the slope is merely called attenuation slope (dB/cm/MHz), which is calculated as follows. Using the least squares method, a linear function is fitted to the attenuation coefficient calculated by substituting the observed spectra into equation (2), and attenuation slope is given by the slope of the fitted line. The frequency range utilized for fitting is limited within the band where the spectral intensity is higher than the noise level. The attenuation coefficient at the center of this range $\alpha(f_0)$ is also calculated, which we call attenuation value (dB/cm).

However, if an ROI is established for the measurement of frequency dependent attenuation inside a tumor showing little internal echo like a cyst, the attenuation coefficient cannot be obtained precisely. For this reason we established the ROI on the wall of the tumor, and proposed a method of using the spectrum of the boundary echoes [5].

As shown in Fig. 5 (a), an example can be considered in which the medium (2) of length (l) has Z_2 acoustic impedance and is partitioned by 2 membranes. The membranes are in contact with media (1) and (3) having impedances of Z_1 and Z_3. The impedances of the two membranes are equal at Z_m, but the thicknesses are different, being d_a for the anterior surface and d_b for the posterior surface. When an ultrasonic pulse $E_s(t)$ is emitted from an oscillator, echoes $E_a(t)$ and $E_b(t)$ return from the two boundary surfaces in contact with medium 2. When spectra of these signals are expressed as $P_s(f)$, $P_a(f)$

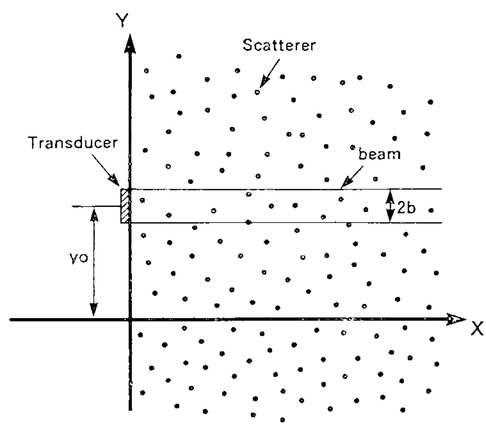


Fig. 4. — A model of the object.

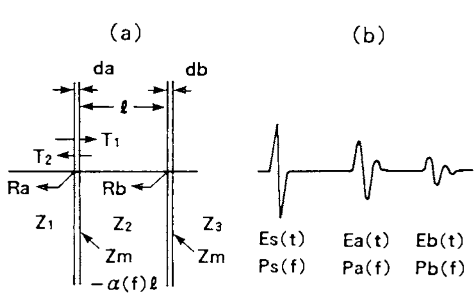


Fig. 5. — *a*) Principle of boundary echo spectrum method; *b*) Waveforms of echoes.

and P_b (f), respectively, the following relation can be established.

$$P_a (f) = P_s (f) \cdot R_a (f) \quad (4)$$

$$P_b (f) = P_s (f) \cdot T_1 (f) \cdot T_2 (f) \cdot R_b (f) \cdot \mathrm{Exp}\{-2\alpha (f) \cdot 1\} \quad (5)$$

Here R_a and R_b are the reflection coefficients of the sound waves from the boundaries of the anterior and posterior surfaces of medium 2, and T_2 are the transmission coefficients of outgoing and returning sound waves passing through the anterior boundary surface (form here, f expressing a function is omitted in some cases). In the situation above, the following formula can be obtained:

$$G (f) = \ln(P_a/P_b) = 2\alpha (f) \cdot 1 + \ln(R_a/T_1 \cdot T_2 \cdot R_b) \quad (6)$$

where α (f) $= \alpha_0 \cdot$ f, and the difference of impedance between the tissues surrounding the cyst fluid is considered to be fairly small ($T_1 \cdot T_2 = 1$). When these conditions are substituted in formula (6), the following formula is obtained.

$$G (f) = 2 \alpha_0 \cdot f \cdot 1 + \ln (R_a/R_b) \quad (7)$$

Further dividing equation (7) by the round trip path length 21, we obtain

$$H (f) = G (f)/21 = \alpha_0 \cdot f + \beta \quad (8\text{-a})$$

and

$$\beta = \mathrm{In} (R_a/R_b)/21 \quad (8\text{-b})$$

Where H (f) is a known function determined by the spectra reflected at the anterior and posterior surfaces and the length between them. From equation (8-a), attenuation slope α_0 can be estimated by removing the effect of reflection coefficient β in H (f), the reflection coefficient R_a (or R_b) is a periodic function of frequency whose period is $v/(2d_a)$ (or $v/(2d_b)$), which causes periodicity on β. Therefore, the slope of the line fitted to H (f) within the range much wider than the period of β is rarely affected by β, so that the slope can be a good estimate of α_0.

$$\alpha_0 = \{ G (f_2) - G (f_1) \}/2l (f_2 - f_1) \quad (9)$$

We call this method the boundary echo spectrum method (5). We confirmed experimentally that the FDA values obtained by the boundary echo spectrum method and the transmission method showed good agreement. Therefore, in this study attenuation slope and attenuation value were obtained using the boundary echo spectrum method.

To confirm the accuracy of our measurements, we used 7 serous cystadenomas, 3 mucinous cystadenomas, 6 endometrial cysts, and 4 dermoid cysts. The extirpated cysts themselves or the cyst contents were placed or injected into ruber bags and fixed in a water bath filled with degassed water. Data collection and processing were then performed by a water immersion method using similar techniques to the procedures described above.

RESULTS

From the transabdominal ultrasonic method, the serous cystadenomas had an attenuation slope (mean±SD) of 0.26±0.10 dB/cm/MHz, and the attenuation value was 0.69±0.79 dB/cm. For mucinous cystadenomas, the attenuation slope was 0.27±0.08 dB/cm/MHz and the attenuation value was 0.85±0.46 dB/cm, and no significant difference was noted between these two types of cyst by Welch's t-test. However, for endometrial cysts the attenuation slope was 0.67±0.27 dB/cm/MHz and the attenuation value was 1.85±1.27 dB/cm, while for dermoid cyst (fat) the attenuation slope was 0.62±0.26 dB/cm/MHz and the attenuation value was 1.86±1.20 dB/cm. Both types of cysts had significantly higher attenuation slope ($P<0.01$) and attenuation value ($p<0.05$) compared with the former two types by Welch's t-test (Table 2, Fig. 6).

In the water immersion study, attenuation slope and attenuation value were low for both serous and mucinous cystadenomas, and no significant difference was noted between them as in the transabdominal study. For endometrial and dermoid cysts, the attenuation slope was significantly higher compared with the former two types of cyst ($p<0.01$), but the attenuation value was only slightly higher and showed no significant difference by Welch's t-test (Table 3).

The correlations were examined between the attenuation slope measured by the transabdominal and water immersion

Table 2. — *Average of attenuation values and attenuation slopes of cystic ovarian tumors with transabdominal method.*

Histological type	Attenuation value (mean ± SD) (dB/cm)	Attenuation slope (mean ± SD) (dB/cm/MHz)
Endometrial cyst	1.85 ± 1.27	0.67 ± 0.27
Cystadenoma		
serous	0.69 ± 0.79 *	0.26 ± 0.10 **
mucinous	0.85 ± 0.46 *	0.27 ± 0.08 **
Dermoid cyst (fat)	1.86 ± 1.20	0.62 ± 0.26

(*) $p < 0.05$, (**) $p < 0.01$.

Endometrial cyst has significantly higher attenuation value and attenuation slope compared with serous and mucinous cystadenomas by Welch's t-test.

methods, and the correlation coefficient was found to be a high 0.94 (Fig. 7). However, for the attenuation values the correlation coefficient was only 0.23 and no correlation was noted.

DISCUSSION

Ovarian endometriosis can be regarded as single cysts or a solid tumor ultrasonically ([6]). Sometimes the internal echo of endometrial cyst is free, but sometimes it is as strong as solid tumor. The variable echographc appearance from a cystic to a solid pattern can be related to the amount and distribution of hemorrhagic debris and fibrous tissue ([7]). Coleman *et al.* showed a cystic, mixed lesion with shaggy and irregular walls, occasional evidence of septation and low-level fine echoes occurring in the dependent on more peripheral portions of the mass as a typical image ([8]). So it is often difficult in practice to differentiate endometriosis from other cysts and tumors by the ultrasonogram alone.

Table 3. — *Average of attenuation value and attenuation slope of cystic ovarian tumors with immersion method.*

Histological type	Attenuation value (mean ± SD) (dB/cm)	Attenuation slope (mean ± SD) (dB/cm/MHz)
Endometrial cyst	1.11 ± 0.78	0.63 ± 0.13
Cystadenoma		
serous	0.67 ± 0.59	0.35 ± 0.11 **
mucinous	0.79 ± 0.13	0.30 ± 0.10 **
Dermoid cyst (fat)	1.45 ± 1.28	0.84 ± 0.18

(**) $p < 0.01$.

Endometrial cyst has significantly higher attenuation slope compared with serous and mucinous cystadenomas by Welch's t-test.

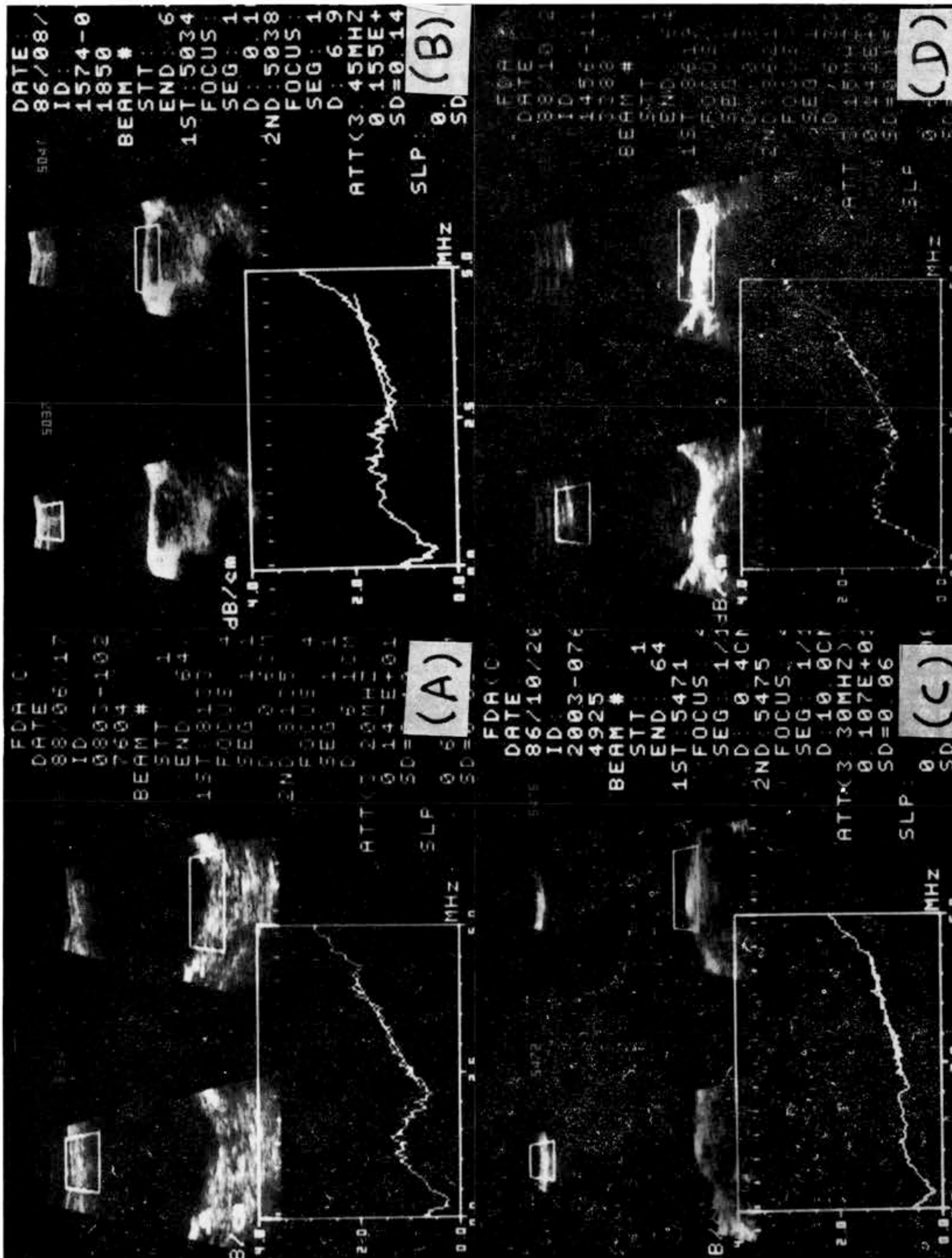
On the other hand, frequency dependent attenuation can be assessed by the spectral difference method or the spectral shift method. The following three methods are presented:

1) Spectral difference method: this method was proposed by Kuc *et al.* ([9]). Ultrasound signals from 2 regions are processed by FFT to obtain power spectra, and from the difference between the regions a coefficient of attenuation is obtained.

2) Spectral shift mean frequency method: this method was proposed by Fink *et al.* ([10]), and is also called short time Fourier analysis (STFA). Ultrasound RF signals obtained in a very short defined time period and processed by FFT, and a coefficient of attenuation is obtained by comparing the center frequency to the distance.

3) Spectral shift zero crossing method: this method was proposed by Flax *et al.* ([11]). In it, a coefficient of attenuation is obtained by measuring the number of

Fig. 6. — Characteristics of attenuation of each ovarian cyst. – A) *Endometrial cyst.* Attenuation slope is 0.697 dB/cm/MHz and attenuation value is 1.47 dB/cm; B) *Serous cystadenoma.* Attenuation slope is 0.340 dB/cm/MHz and attenuation value is 1.55 dB/cm; C) *Mucinous cystadenoma.* Attenuation slope is 0.299 dB/cm/MHz and attenuation value is 1.07 dB/cm; D) *Dermoid cyst.* Attenuation slope is 0.643 dB/cm/MHz and attenuation value is 1.42 dB/cm.


(A)
(B)
(C)
(D)
dB/cm
MHz

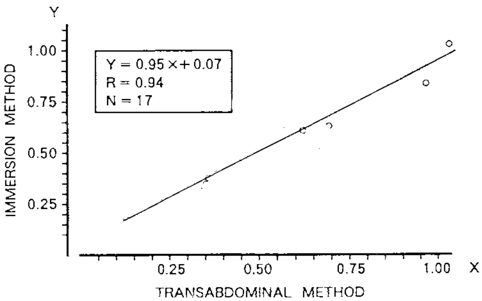


Fig. 7. — Correlation of the attenuation slope between transabdominal and immersion method.

times of passing zero in a defined time period.

The spectral shift methods, including the mean frequency and the zero-crossing method, require the spectral variance in echo signal to estimate the frequency dependent attenuation. Usually, the incident spectrum is assumed to be Gaussian, because its variance remains constant when the attenuation constant is proportional to frequency. The incident spectrum is, however, offen different from Gaussian shape. Therefore, we used the spectral difference method which is applicable to an arbitrary spectrum, though it requires a time consuming process.

There are reports available on the frequency dependent attenuation in liver disease ([12]) and uterine myoma ([2]), but none have been published concerning cystic lesions. In the case of a cystic lesion such as ovarian cyst the internal echo is weak, and if an ROI is established in the interior of the cyst, the attenuation coefficient cannot be obtained accurately. We therefore proposed the boundary echo spectrum method ([5]) for such cystic lesions, and obtainel the ultrasonic attenuation characteristics of ovarian cysts by this method.

Characteristic changes of the attenuation value and attenuation slope were noted, but it is considered that the attenuation slope is superior for the following reasons.

1) The overall standard deviation of the attenuation slope was smaller than that of the attenuation value.

2) In the same lesions, when the attenuation slope and attenuation value for the water immersion and transabdominal methods were compared, there was a stronger correlation between the attenuation slopes than between the attenuation values.

In this study, the frequency depending attenuation of ultrasound was measured in ovarian cysts, and differences in the attenuation characteristics due to the type of tissue were investigated. It was found that endometrial cysts showed significantly higher attenuation slopes and attenuation values compared with serous and mucinous ovarian cysts. So, it became easy by to differentiate accurately the endometrial cyst from the other ovarian cysts, except for dermoid cyst. But the endometrial cyst showed similar attenuation slope and attenuation values to those of the fat component of dermoid cysts. Therefore, in the case of dermoid cysts composed of fat and a small amount of hair, no distinction can be made from endometrial cysts on the basis of frequency dependent attenuation. However, it is well known that hair shows a characteristic hair line on ultrasonograms ([13, 14, 15]). And dermoid cyst often showed central high echo and posterior accoustic shadow because of hair ball in the cyst ([15]) or horizontal line because of difference of components ([15]) and often contained dermoid plug ([15, 16]). So these conditions can often be differentiated on B-mode images. Thus, the differentiation of diagnosis of endometrial and other ovarian cysts can be corrected by using ultrasonographic finding and ultrasonic frequency dependent attenuation.

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