Paper

A New Approach to Ultrasonic Tissue Characterization on Second Harmonic Component of 100 MHz

Toshihiro Nishimura[*] Member
Akira Kubota[**] Member
SozaboruYoshihara[***] Member
Hiroshi Kanda[****] Member
Syoichi Senda[*5] Non-member
Masao Saito[*6] Member

In order to evaluate the properties of ultrasonic nonlinear scattering, the ultrasonic attenuation characteristics using the second harmonic component of the transmitted ultrasonic signal through normal and fatty hen liver as well as the fundamental component were measured. In The experiment, a 50MHz transducer was by reflection method and its frequency dependency was analyzed. The second harmonic component was detected by using pulse inversion detection technique. The experimental results showed that the attenuation coefficient was almost constant around second harmonic frequency dependence can identify the property of normal and fatty hen liver.

Keywords : Ultrasonic tissue characterization, Ultrasonic attenuation, Tissue harmonic component, Fatty liver, Pulse inversion detection, Relaxation of side chain of protein

1. Introduction

Ultrasonic tissue characterization[(2)-(6)], which is a relatively mature technique, has been a very important procedure in medical diagnoses. Acoustic parameters of tissue change according to their physical and chemical properties. Ultrasonic attenuation is one of the most significant indices used to estimate tissue characteristics.

Ultrasonic attenuation characteristics of many biomedical tissues, such as liver tissue and myocardium, have been measured and discussed over the last forty years; however, ultrasonic attenuation characteristics in the frequency range higher than 10MHz have hardly been reported. In the frequency range lower than 10MHz, ultrasonic attenuation of tissues, which are composed of macromolecules, is caused by the hydrolysis of amino acids, as well as, the relaxation process of the protein's side chain. Measuring ultrasonic attenuation in this high frequency range is important in estimating the micro-physical structure of biomedical tissue. Based on this concept, the ultrasonic attenuation characteristics and attenuation coefficient of the protein in the high frequency range between 30MHz and 70MHz were measured using 50 MHz ultrasonic transducer[(7)-(9)].

In this paper, ultrasonic attenuation of the second harmonic component is also measured, which is caused by nonlinear scattering of tissue to explore further possibilities in ultrasonic tissue characterization. In order to obtain the second harmonic component of the echo, a pulse inversion detection technique(1) is used that has been developed for detecting nonlinear scattering. In this technique, two pulses are transmitted, one of which is an inverted copy of the other. For nonlinear scattering, the two received echoes contain, not only, the fundamental component but also its harmonic components. The fundamental components of the two echoes are inverted with respect to each other-but the second harmonic components are inphase. Based on this principle, the pulse inversion detection technique uses the sum signal of the two echoes, which cancels the fundamental component and, thus, contains only harmonic components, in which the second harmonic component is typically dominant. Therefore, the pulse inversion detection technique can detect the harmonic component without filtering. As a result, it largely overcomes contrast/resolution tradeoffs inherent in harmonic imaging techniques. In the experiment, ultrasonic attenuation is measured at the second harmonic frequency on fatty and normal hen liver.

2. Measurement of Ultrasonic Attenuation

In this section, the method used to measure the ultrasonic attenuation of the fundamental and the second harmonic components of the ultrasonic signal is described. The conventional reflection method for measuring ultrasonic attenuation was used. To detect the second harmonic component of the ultrasonic signal, a proposed technique called "pulse inversion detection technique", which detects the second harmonic component, eliminating the fundamental component was used.

2.1 Principle of Measuring the Frequency-Dependent Ultrasonic Attenuation by Reflection Method and its Frequency Dependence Analysis Ultrasonic attenuation of

[*] Waseda University Graduate School, Information Architecture
2-2, Hibikino Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0135
[**] The University of Tokyo Faculty of Engineering
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8654
[***] Oita Education Center
847-2, Dannoharu, oaza, Oita-shi 870-1124
[****] Hitachi Medical co. ltd
2-1, Shi-Toyofutaura, Kashiwa-shi 277-0804
[*5] Department of Intergrated Medicine Kagawa Unibersity Shool of Medicine
1750-1, Ikenobe, Miki-cho, Kita-gun, Kagawa 761-0793
[*6] Tokyo Denki University Faculty of Engineering
2-2, Kanda-Nishiki-cho, Chiyoda-ku, Tokyo 101-8457

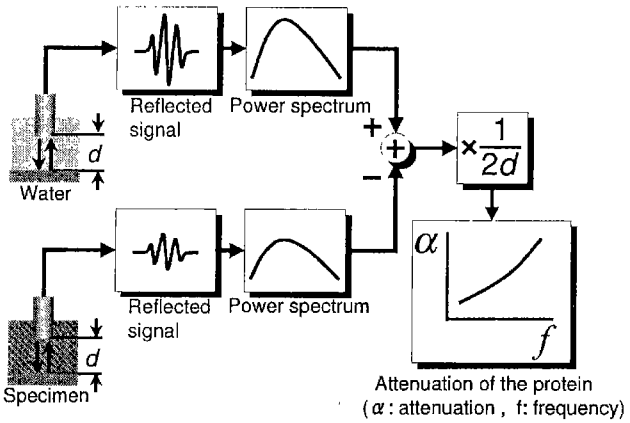

Fig. 1. Ultrasonic attenuation measurement system by reflection method. The difference of the power spectrum of the reflected ultrasonic signals in the water and the specimen is normalized by propagation distance $2d$.

the specimen was measured using the reflection method. This method requires a transducer that can transmit and receive. Experimental setup is described in section 3. Figure 1 illustrates a block diagram of the attenuation measurement system. The ultrasound signal transmitted and reflected through the specimen was received by the transducer and its power spectrum was calculated. The procedure to determine the attenuation of the specimen is as follows:

(1) Measure the power spectrum of the ultrasonic signal propagated in the specimen and that of the ultrasonic signal propagated in distilled water.
(2) Subtract the power spectrum of the specimen from that of the distilled water.
(3) Normalize this power spectrum difference by twice the focus distance that the ultrasound propagated.

Thus, the attenuation $\alpha(f)$ is evaluated by the following equation:

$$\alpha(f)=\frac{P_w(f)-P_s(f)}{2d} \quad \cdots\cdots (1)$$

where, $P_w(f)$, ahd $P_s(f)$ are the measured power spectrum of the water and that of the specimen, respectively, and d is the distance between the transducer and the reflector.

Ultrasonic attenuation depends on the frequency of the ultrasonic signal. The dependency can be evaluated by the constant k which is defined as the coefficient in the following equation:

$$\alpha(f)\propto f^k \quad \cdots\cdots (2)$$

based on the linear relationship between the attenuation and frequency. The coefficient k, which is one of the indices often used for characterizing tissue, can be determined by the proportion coefficient of the logarithm of $\alpha(f)$ to that of frequency f.

2.2 Principle of Pulse Inversion Detection Technique[1]

Let us explain the principle of pulse inversion detection technique in brief. The developed technique for detecting nonlinear scattering, that is; pulse inversion detection, has been proposed(1). In this method, two pulses are used, which are inverted with respect to each other as follows:

$$p_2(t)=-p_1(t-T) \quad \cdots\cdots (3)$$

where p_1(t) and $p_2(t)$ represent the acoustic pressure of the first and the second pulse at time t, and T is delay time. Letting

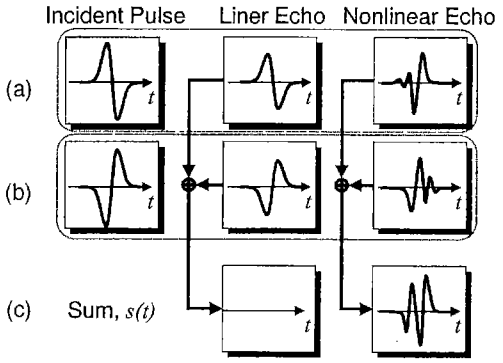

Fig. 2. Principle of pulse inversion detection[1]: (a) an incident pulse and echoes from linear and nonlinear scattering; (b) the inverted incident pulse of the same pulse and the echoes; (c) the sum signal of two echoes. For linear scattering, the sum is zero. For nonlinear scattering, the sum is nonzero.

$Echo\{p_i(t)\}$ be the received echoes produced by the incident pulse $p_i(t)$ for i=1, 2, we form the pulse inversion detection as the summation of these two echoes:

$$s(t)=Echo\{p_1(t-T)\}+Echo\{p_2(t)\} \quad \cdots\cdots (4)$$

For linear scattering, $s(t)$ will be zero, since $Echo\{-p_i(t)\}=-Echo\{-p_i(t)\}$, under the condition that there is no relative motion between the transducer and scatter. For nonlinear scattering, $s(t)$ will be not zero, as shown in fig. 2. Assuming a simple model of nonlinear scattering where echo is represented as (more than three order term is supposed to be ignored for easy explanation)

$$Echo\{p_i(t)\}=a_1p_i(t-\tau)+a_2p_i^2(t-\tau) \quad \cdots\cdots (5)$$

for i=1,2

where τ is a time delay, we obtain:

$$s(t)=2a_2p_i^2(t-\tau) \quad \cdots\cdots (6)$$

The sum signal. $s(t)$, contains only the second order of $p(t-\tau)$, which gives rise to the second harmonic of the transmitted signal. As a result, the harmonic caused by nonlinear scattering can be detected.

2.3 Principle of Measuring Frequency-Dependent Ultrasonic Attenuation of the Second Harmonic Component

A reflection method is also used for measuring ultrasonic

attenuation of the second harmonic component. Firstly, the first pulse, $p_1(t)$, is transmitted through the specimen and the reflected signal is received and memorized. Next , the second pulse, $p_2(t)$, which is an inverted version of $p_1(t)$, is transmitted into the specimen and the reflected signal is received. These two reflected signals are summed to obtain the signal $s(t)$, and then its power spectrum, $P'_s(f)$, is calculated. The power spectrum, $P'_w(f)$, for water instead of the specimen is also calculated in the same procedure. Ultrasonic attenuation of the second harmonic component, $\alpha'(f)$, is obtained by

$$\alpha'(f)=\frac{P'_w(f)-P'_s(f)}{2d} \quad \cdots\cdots (7)$$

where $2d$ is the two-way path of the transmitting signal. Ultrasonic attenuation, $\alpha'(f)$,will represent the attenuation of the harmonic component caused by nonlinear scattering of the specimen.

3. Experiments and Discussion

3.1 Experimental Setup Figure 3 shows the measurement system used in the experiment. A transducer (caliber: 0.25", focal distance: 12mm) with a center frequency of 50MHz was used for both transmitting and receiving a ultrasonic signal that is controlled by an ultrasonic analyzer (PANAMETRICS MODEL 5600T). The transducer was located perpendicular to the plane of the reflector in the tank filled with the specimen or water (see fig. 3). The distance between the reflector and the transducer was 12mm, which is equal to the focal distance of the transducer. Power spectrum of the received ultrasonic signal was calculated by a digital signal processor (PHLIPS PM3323), which was connected to computer with GPIP.

In our experiment, homogenized fatty (the rate of fat is more than 12%) and normal (the rate of fat is less than 3%) hen liver, each mixed with physiological salt solution, were used as the specimens. It was reported that the attenuation coefficient was hardly affected by the homogenization[4]. And also, haw the coefficient k is changed by the concentration and temperature of protein was evaluated.

3.2 Experimental Results on Fundamental Component and Discussion The attenuation of the protein (gelatin solution) with concentration of 4% and 8% was measured when the temperature was decreased from 50℃ to 25℃. To evaluate how attenuation depends on the frequency, attenuation as a function of the frequency was analyzed and the regression coefficient between the logarithm of the attenuation and that of the frequency was calculated. In tissue characterization, both the attenuation value and this coefficient are important indices.

Figure 4 shows the power spectrum of the ultrasonic signal propagated in water at 25℃ and in the 4% and 8% concentration gelatin at 25℃. The magnitude of the power spectrum of the protein is smaller and its center frequency is lower than that of the

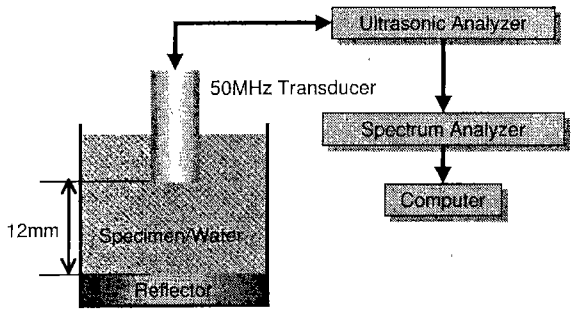

Fig. 3. Measurement system for experiment using reflection method. 50MHz transducer and ultrasonic analyzer are used to transmit and receive ultrasonic signal.

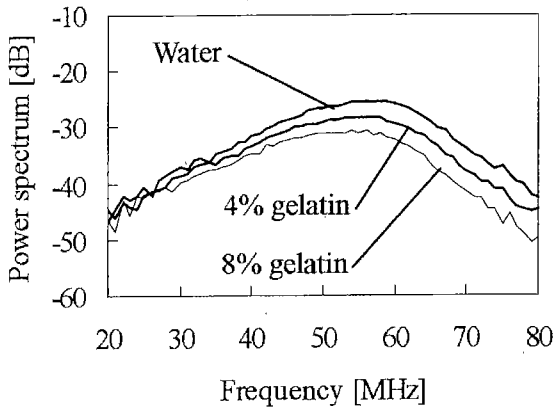

Fig. 4. Power spectrum of the ultrasonic signal propagated through the water, 4% and 8% concentrated gelatin solution at 25℃.

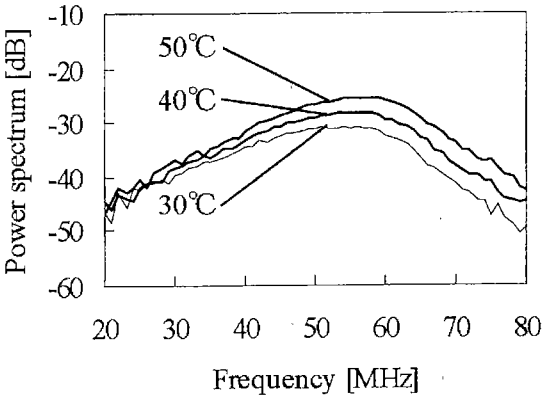

Fig. 5. Power spectrum of the ultrasonic signal propagated through the 8% concentrated gelatin solution at 30℃, 40℃ and 50℃.

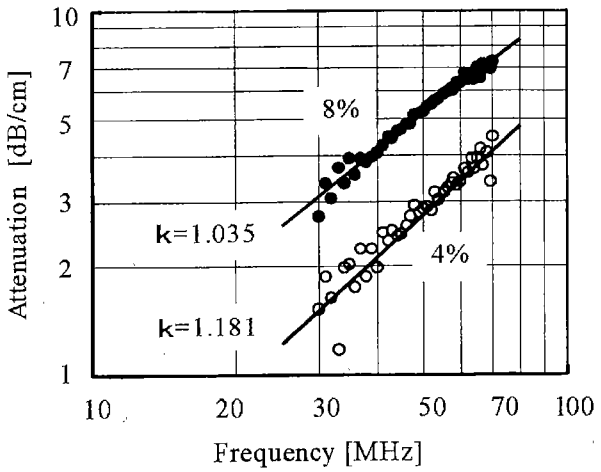

Fig. 6. Ultrasonic attenuation of the 4% and 8% concentrated gelatin at 35℃ plotted on log-log axes. Constant k indicates the proportion of logarithm of attenuation to that of frequency.

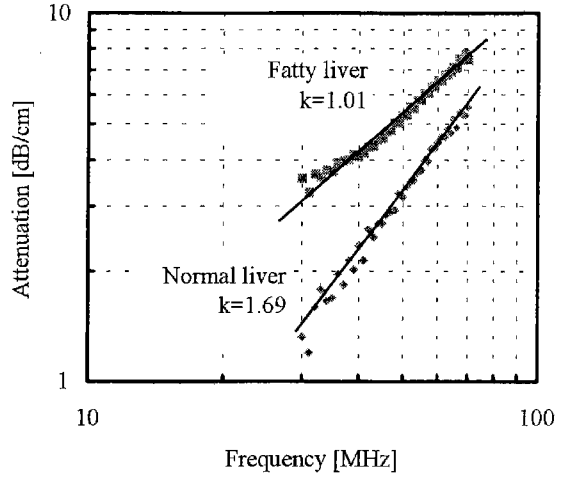

Fig. 7. Ultrasonic attenuation of the normal and fatty hen liver at 40℃.

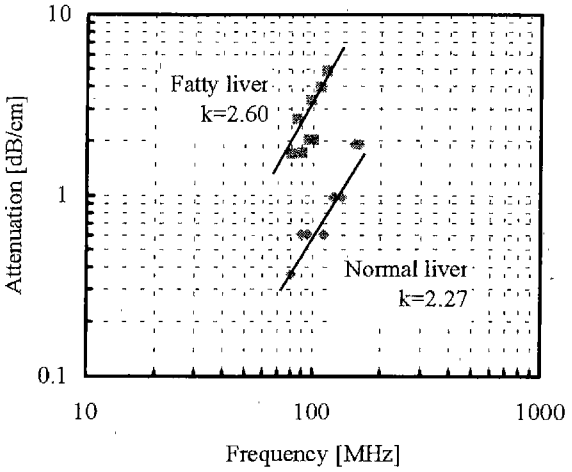

Fig. 8. Ultrasonic attenuation of the normal and fatty hen liver at 40℃ for second harmonic component.

water. The attenuation of 8% concentration gelatin in the 30-70MHz range when the temperature is decreased from 50 to 30℃ is shown in Fig.5. This results clearly shows that attenuation increases with frequency and decreases with temperature. At 50MHz, the attenuation of gelatin at 30℃ is 4.85 dB/cm, which is larger than that of the same gelatin at 50℃ by 2.1 dB/cm. The large attenuation at low temperature may be due to gelatin coagulation.

Figure 6 shows the attenuation characteristics of the gelatin at 30℃ plotted on log-log axes. Constant k denotes the regression coefficient and was around 1.1 for both concentrations. The relationship between the logarithm of the attenuation and that of frequency was almost proportional to frequency to the 1.1th power. It also suggests that attenuation depends on the concentration of protein, but the coefficient k is independent of the concentration.

Figure 7 shows the attenuation characteristics of the normal and fatty hen liver at 40℃ plotted on log-log axes. It can be seen that the relationship between the logarithm of the attenuation and that of frequency is almost linear and its slop, i.e. the coefficient k, for normal liver differs from that for fatty liver. Thus, the property of the tissue, normal of fatty, can be characterized by the difference of the coefficient k.

3.3 Experimental Results at Second Harmonic Component and Discussion Figure 3.3 shows the measured ultrasonic attenuation characteristics of normal and fatty hen liver at second harmonic component at 40℃ plotted on log-log axes. The pulse inversion pulse $s(t)$ contains harmonic components of 100MHz, because The center frequency of the incident ultrasound pulse is 50MHz. In fig. 8, the ultrasonic attenuation in the frequency band from 80MHz to 120MHz was measured. The second harmonic component was seemed to be the most dominant component in the detected pulse $s(t)$ and the other higher order components were not able to be correctly measured due to noise. From fig. 8, it can be seen that the relationship between the logarithm of $a(f)$ and that of frequency is approximately linear. In Fig. 8, the slope was almost constant for both normal and fatty hen livers. In this experiment, there is a difference of the slope which characterize the tissue property between normal and fatty livers. In the case of the second harmonic component, the slop for fatty liver is larger than that for normal liver. This is inverse to the result for the fundamental component (Fig. 7).

4. Conclusion

In this paper the ultrasonic attenuation of normal and fatty liver was measured, using both the fundamental and the second harmonic echo signal using 50MHz.ultrasonic pulse. The slope of the ultrasonic attenuation and discussed the difference between normal and fatty hen liver was analyzed. From the experiment's results, the follows are concluded:

(1) Attenuation of the protein increase as temperature falls.
(2) Regression coefficient between the attenuation and frequency is independent of the concentration of the protein.
(3) The coefficient is different between normal and fatty hen liver for both the fundamental and the second harmonic component. In the case using the fundamental component, the coefficient for normal liver is larger than for fatty liver, On the other hand, in the case using the second harmonic component, coefficient for normal liver is smaller than for fatty liver.

The 3rd conclusion suggests that the difference of frequency dependence can identify the property of normal and fatty hen liver, leading to the possibility of new tissue characterization using second harmonic component.

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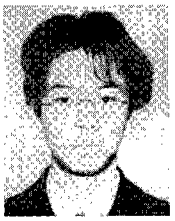
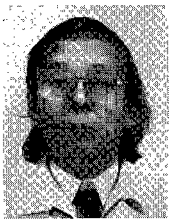
Toshihiro Nishimura (Member) is currently a professor of Information Architecture, Waseda University Graduate school of Information, Production and System since 2003. He received the Dr.-Eng. Degree from the University of Tokyo. His research interests are the nerve physiology, cardiovascular system, artificial human retina, COMS Image sensor, Medical Ultrasonic Imaging, Neural network, Self organized map, and all the power electronics on human affairs and space missions. He is currently Chairman of Committee on Medical & Biological Engineering IEE Japan, Trustee of Medical Ultrasonics Society, Councilor of IEEE power Electronics Society and a Member of IECIE, JSMBE, IEEJ and IEEE. He is decorated society of IEEJ-C for the contribution award in 2002, and et. al. e-mail : tosi-hiro@waseda.jp

Akira Kubota (Member) is currently a research associate at Research Fellowships of the Japan society for young scientist of the University of Tokyo. He received the B. E. degree from the University of Oita and received the Master of Eng. And Dr.-Eng. Dgree from the University of Tokyo respectively. His interests are Image processing and visual Information processing. He is a member of IECIE, IEEJ.



Souzaburou Yoshihara (Member) is currently a chief researcher of Oita Prefecture Institute of Education. He received the B. E. and Master of Eng. Degree from the University of Oita. His research interests are the nerve physiology, cardiovascular system, and Medical Ultrasonic Imaging. He is a member of IEE Japan.

Hiroshi Kanda (Member) is currently a Senior Chief Engineer, Ultrasound division, Hitachi Medical Corporation. He received the B. E. degree, the Master of Eng. And Dr-Eng. Degree from the University of Tokyo respectively. His interests are Image processing on Ultrasonic. He is a member of IECIE, IEEJ.



Shoichi Senda (Non-member) is currently a professor of integrated diagnostic division of Kagawa Medical University. He received the Dr.-Med. & PhD. degree from the Osaka University. He is a Trustee of Medical Ultrasonics Society, and JSMBE.

Masao Saito (Member) is currently a professor of Tokyo Denki University. He received B. E., M. E. and the Dr-Eng. Degree from the University of Tokyo. His research interests are Human Science. Medical Ultrasonic Imaging, affairs. He is a Member of IECIE, JSMBE, IEEJ and IEEE. He is decorated awards so many all over the world. He also serves lots of Japan govemment committee to Life & Welfare Science.