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Development of Non-Uniform Breast Phantom and Its Microwave Imaging for Tumor Detection by CP-MCT

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Abstract—**Phantom model of the breast which has actual shape and size has been developed for evaluation of microwave imaging by Chirp Pulse Microwave Computed Tomography (CP-MCT). This phantom model will also be successfully used for hyperthermia experiments using microwaves. This phantom model is consisted of four kinds of tissue mimicking materials, that is, the skin-, breast fat-, muscle-, and tumor-simulators. The principal ingredients of the phantom are water, liquid paraffin, super stuff (TX-150), sugar, and salt. It is easy to simulate permittivity of the real breasts in addition to the shape and size. This is the advantage of this non-homogeneous phantom. CP-MCT is a modality for microwave imaging of a human body using chirp pulse microwaves to extract the component which transmits the straight path between two antennas. Possibility of tumor detection by CP-MCT has been demonstrated by using the higher frequency model of CP-MCT and the non-homogeneous breast phantom.**

I. Introduction

It will be very useful to establish the fabrication method of realistic phantom model of the breast which is non-uniform in dielectric property and looks like a real breast in respect of the shape and size. The breast phantom developed here in this study was originally desired to build for microwave imaging by Chirp Pulse Microwave Computed Tomography (CP-MCT). CP-MCT is a microwave imaging modality for visualizing various functions of a human body [1-3]. One of the possible applications is image diagnosis of the early stage breast tumors.

The CP-MCT-based image diagnosis will become more useful if complementary information provided by Chirp Pulse Microwave Breast Radar (CP-MBR) is available. Where, CP-MBR is a kind of chirp radar which detects breast tumors by making use of the same principle as CP-MCT [4, 5]. In order to demonstrate the usefulness of our methodology, this phantom will play important roles in the experimental stage.

Many papers on breast tumor detection have been published up to now [6, 7]. Ultra Wide Band (UWB) pulse radars are often used to localize the small tumors in the breasts [8]. It is well known that the key technology for those breast radars is a discrimination method of scattered waves by the skin from the reflected tumor signal. Since the scattering waves are also affected by the thickness of the skin, non-uniform breast phantoms developed in this study will be used effectively for the experimental studies for such UWB radars.

In the first half of the paper, the fabrication method and dielectric properties of the non-uniform breast phantom are described. In the latter half of this paper, imaging possibility of the early stage breast tumors using CP-MCT is demonstrated. Needless to say, this phantom will successfully be used for evaluation of the treatment effects of hyperthermia using microwaves.

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II. Fabrication and Permittivity

A. Basic Structure

The shape and size of the developed breast phantom are not standardized ones. But they are typical Japanese women's ones because they were determined by a mannequin (tailor's dummy) as the molding flask of the phantom. The rough description of the model dimension is given in Fig. 1. As shown in this figure, the phantom is consisted of four kinds of simulated tissues. It should be noted that this phantom is actually not bilateral symmetry.

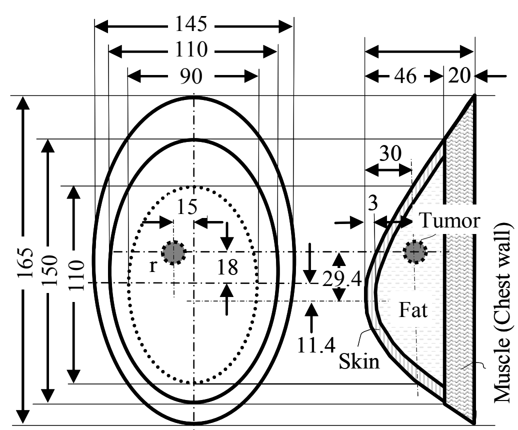


Fig. 1 Fundamental structure of the developed breast model

B. Permittivity and Its Stability

Composition and complex permittivity of those simulated tissues are given in Table 1. In the fabrication process of the breast fat, pure water and isoparaffin are mixed in the combination ratio of 7.4:2.6 so that those weight ratios become approximately 49.1 % and 15.5 % as shown in Table 1. Similar description is given in the weight ratio of super stuff (TX-150) in the simulated skin. The amount of "42.0 %" is the approximated one in Table 1. TX-150 was so added as to become the total amount of constituents of the simulated tissues 100 percent.

Permittivity values of the simulated tissues were evaluated by using dielectric coaxial probe, HP-8570B and network analyzer, HP-8720ES in the frequency range from 1.0 to 4.0 GHz. In Table 1, permittivity values are given by relative dielectric constant ε' and conductivity σ S/m at 2.5 GHz. This is the center frequency of the chirp pulse signal used in CP-MCT. Subscript *s* means the reference value of permittivity that is available at the well known website http://niremf.ifac.cnr.it/tisprop/ [9]. Conductivity of the skin has an error of approximately ten percent, but the other permittivity values show good agreement with the reference values. We have never tried to fabricate tumor simulators in this study, because the permittivity value is not necessarily clear. Instead, we used the simulated muscle to fabricate spherical shaped tumors 15 or 20 mm in diameter in this study. Figure 2(a), (b) show the breast phantom in which spherical tumor 20 mm in diameter was imbedded deeply as shown in Fig. 1. Figure 2(b) was taken by cutting out the breast at the longitudinal section that passes the center of the tumor.

Table 1 Composition of simulated tissues

Simulator of tissues	Constituent	[%] in weight	Relative dielectric constant		Conductivity [S/m]	
			ε'	ε_s'	σ	σ_s
Breast fat	Pure water	(49.1)	5.30	5.14	0.13	0.14
	Isoparaffin*1	(15.5)				
	Salt	0.34				
	Dextrin*2	30.0				
	Surface active agent*3	5.0				
Skin	Pure water	54.0	40.8	42.8	1.79	1.62
	Super stuff	(42.0)				
	Salt	0.05				
	Sugar	4.00				
Muscle	Pure water	65.0	51.7	52.7	1.73	1.77
	Super stuff	35.0				
Tumor	Not developed					

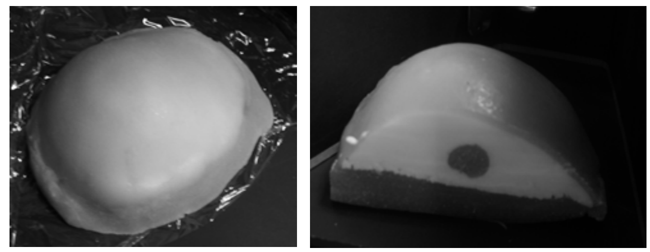
1: "High White 22S", Nippon Oil Corporation, Tokyo, Japan

2: "Rheopearl KL2", Chiba Flour Milling Co. Ltd., Chiba, Japan

3: "Matsunate DI", Matsumoto Fine Chemical Co. Ltd., Chiba, Japan

The surface of the breast phantom is coated by a water-soluble acrylic resin (SY-100, Sunhayato Co. Ltd., Tokyo) three times to prevent the breaking in the bolus saline solution. As a result, dielectric constant of the simulated skin surface is lowered by approximately 7.4% at 2.5 GHz while the conductivity is not varied as shown in Fig. 3. More or less, this would change the scattering characteristics on the skin surface.

These phantom models will be used for several times if the fundamental characteristics are not varied so much. Therefore, the time course of permittivity change is an important characteristic for the simulated tissues.



(a) Air view (b) Cross section view

Fig. 2 Developed phantom of the breast

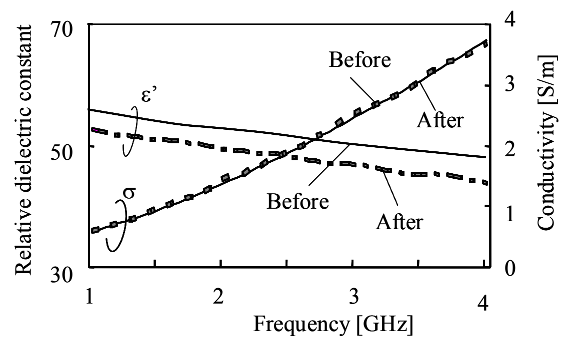


Fig. 3 Permittivity change by coating the phantom

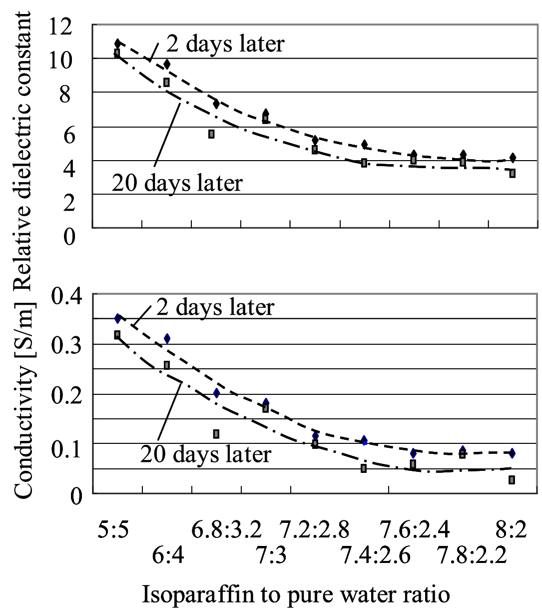
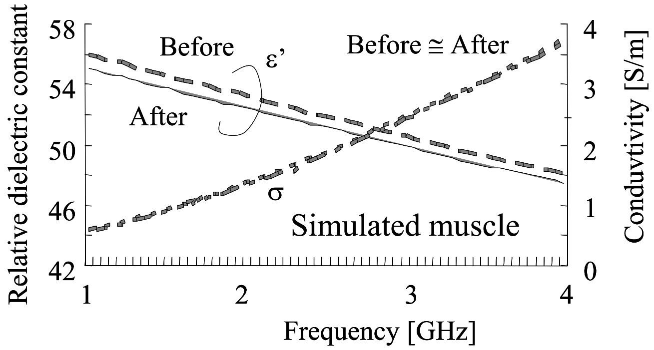
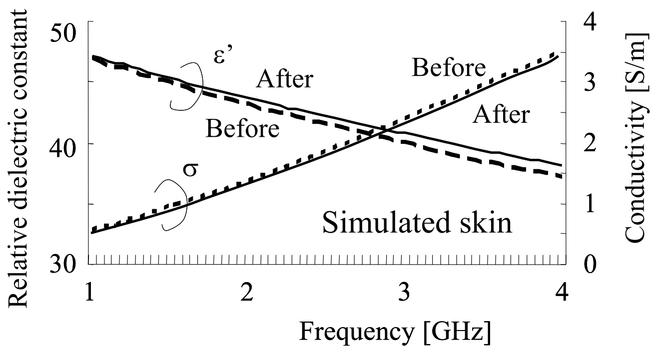


Fig.4 Permittivity change for 20 days

We fabricated nine kinds of breast fat simulators by varying isoparaffin to pure water ratio from 5:5 to 8:2. The other constituents are the same as ones as shown in Table 1. Those fat simulators were preserved for 20 days at a room temperature (about 25 ºC) by wrapping up with a thin film for food packing. Permittivity values were measured 2 or 20 days later from the fabrication day. As shown in Fig. 4, both of dielectric constant and conductivity are lowered by a certain amount of values regardless of the isoparaffin to pure water ratio. In the simulated fat tissue, dielectric constant decreases at the rate of 1.01 %/day, whereas conductivity decreases at the rate of 1.54 %/day. This change is caused by loosing water due to evaporation thru the thin film. However, this change can be decreased by keeping them in a closed vessel that is shut tightly. Anyhow preservative property of the breast fat simulator is fairly good when it is preserved properly.



(a) Simulated muscle covered with simulated fat



(b) Simulated skin covered with simulated fat

Fig. 5 Permittivity change by immersing in the bolus

C. *Contact Permittivity Change*

Four kinds of tissue simulators are used to build the breast phantom as shown in Fig. 1. In such a case, diffusion of the constituents may change the permittivity in the boundary region of both tissue simulators. To examine the effect, permittivity of the surface region of muscle simulator was measured just after the fabrication and 2 days later after fabrication. Room temperature was kept at approximately 21 ºC during this measurement. Permittivity was measured by contacting the coaxial dielectric probe onto the surface of muscle simulator. Figure 5(a) shows the results of this measurement. Slight change is observed in dielectric constant but the change in conductivity is not observed clearly.

The similar effects of tissue contact between the fat- and skin-simulators were evaluated also. As shown in Fig. 5(b), the change in dielectric constant is relatively small as compared to the simulated muscle. On the contrary, conductivity change is small but visible in contrast to the simulated muscle. As well known, the accuracy in phase shift measurement by a network analyzer is not so high as compared to the amplitude measurement. Judging from these facts, permittivity values of developed tissue simulators do not seem to be so affected by contacting to the other simulated tissues.

In conclusion, tissue simulators developed in this study are almost free from permittivity change at the tissue boundaries.

III. Imaging of Breast Tumor by CP-MCT

A. *Setting of Breast Phantom*

Figure 6 demonstrates the breast phantom that was placed in the bolus saline solution of the fan beam scanner of CP-MCT. The surface of the phantom was coated by water-soluble acrylic resin, and it was preserved for several days in the air by wrapping with a thin film for food. Imaging experiments were done by using a chirp pulse signal from 2 to 3 GHz in the saline solution bolus from 0.4 to 0.8 % in weight. The receiving array antenna is consisted of 31 sandwiched dipole array antennas [10], whereas the transmitting antenna is a dielectric-loaded wave-guide antenna. Data acquisition time of this prototype model is approximately five minutes.

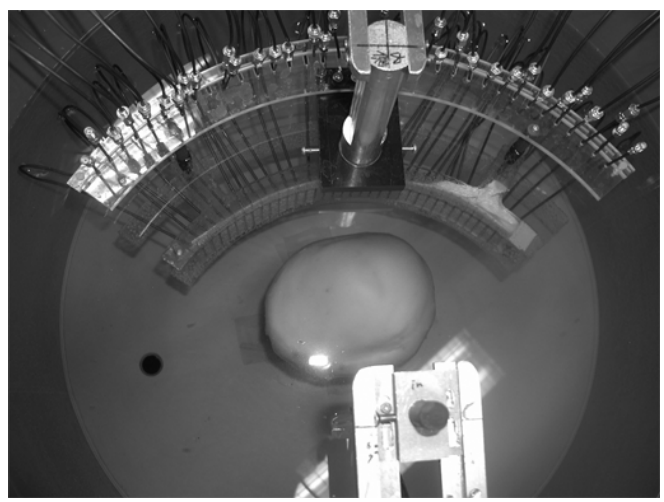
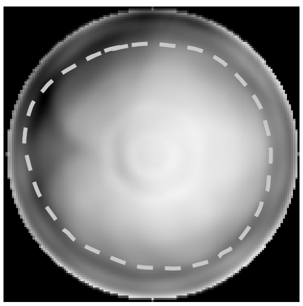


Fig. 6 Developed breast phantom set up in the bolus saline solution of CP-MCT along with the fan-beam scanner

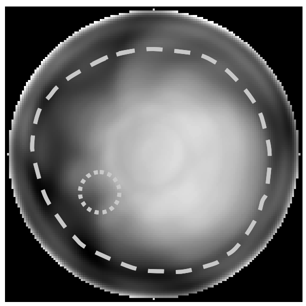
B. *Tomography Imaging*

Microwave imaging of four kinds of breast phantoms that were suffered or not suffered from a tumor 15 or 20 mm in diameter was carried out. The first imaging is a control study, i.e. imaging of the non-diseased breast. The reconstructed image is given in Fig. 7(a). In contrast, Fig. 7(b) is tomogram of the diseased breast phantom. When concentration of the bolus saline solution is 0.4 %, CP-MCT provides the image such as Fig. 7(b). The imaging plane passes the center of the tumor. By simply subtracting Fig. 7(a) from Fig. 7(b), we get Fig. 7(c). Suspected region is not given so clearly, but it is clear that non-symmetrical dark area is found around the tumor. These figures from Fig. 7(a) to Fig. 7(c) were measured when concentration of the bolus saline solution was 0.4 %.

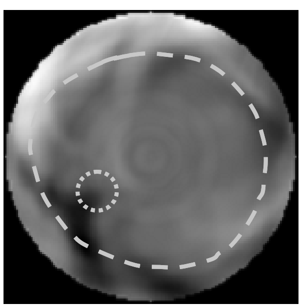
Figure 7(d) and Fig. 7(e) are images of the diseased breast as shown in Fig. 1. However, salt concentrations of the bolus saline solution in Fig. 7(d) and Fig. 7(e) are 0.6 and 0.8 %, respectively. Better indications of the tumor are given from these figures. The best result was obtained when the loss in bolus saline solution is the highest



(a) No tumor imbedded



(b) Tumor 20 mm in diameter

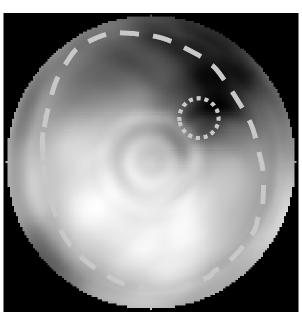


(c): Obtained by subtracting (a) from (b) when concentration of bolus saline solution was 0.4 %

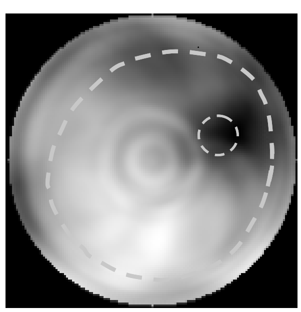
(d): Similar to (c) but concentration of bolus saline solution was 0.6 %

(e): Similar to (c) but concentration of bolus saline solution was 0.8 %

(c) Tumor image (0.4 % S.S. (saline solution))



(d) Tumor image (0.6 % S.S.)



(e) Tumor image (0.8 % S.S.)

Fig. 7 CP-MCT images aiming at tumor detection

IV. Discussion

We have developed new fat tissue simulator which is emulsion gel composition. By using the simulated fat tissue, we have developed the breast phantom model for microwave imaging or heating that is very close to the real breast in respect of dielectric property, size and shape. This phantom is used repeatedly for two weeks or more by preserving in an airtight vessel. In addition to the breast without suffering from any diseases, breasts suffering from a malignant tumor can easily be fabricated.

Microwave imaging of developed breast phantoms which are suffered from a tumor were carried out by making use of CP-MCT. Due to the complex structure of human breast, the accessible region of the microwave scanner is very limited. Nevertheless of this fact, tomograms provided by CP-MCT suggested the possibility of tumor detection by use of CP-MCT.

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