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Imaging of Forearm-Muscle Activities by CP-MCT and TR-DOT

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Abstract—**Chirp Pulse Microwave Computed Tomography (CP-MCT) has been developed to visualize activities of forearm muscles during exercise. The change in the gray levels between two images obtained before and after loading exercises showed position dependence. This was produced by physiological- or biochemical- changes in forearm muscles caused by grasping a rubber ball in the bolus tank that was filled with saline solution. However, nobody knows the truth how this change was produced. In order to infer the mechanism of the gray level change caused by the exercise, the forearm exercise was investigated also by using electromyography and Time-Resolved Diffuse Optical Tomography (TR-DOT). Measurements by CP-MCT and TR-DOT were not performed simultaneously, but both images obtained under the same experimental condition showed similar changes in each tomogram. They were characterized by activation of inner muscles needed for continuing the exercise.**

I. Introduction

CP-MCT was developed for functional imaging of a human body using a chirp pulse microwave [1-3]. It provides the microwave attenuation inside the object dielectric material as an image so that the physical-, chemical-, and physiological-changes inside the human body are visualized through the dependence on the attenuation. In fact, we have reported possibility of visualizing the temperature change [1], malignant tumors [4-6], and high concentration region of sugar or acid [4]. Moreover, we have been investigating visualization method of muscle activities during grip exercise by using CP-MCT [7].

In the attempt of functional imaging, we observed that the gray level change in the central region of the forearm differed from the surrounding region. However, the true reason of this change is not necessarily clear. Changes in temperature, sugar metabolism, oxygen metabolism, and some other physiological conditions may be concerned with the gray level change in CP-MCT image. To examine mechanisms of the gray level change, Time-Resolved Diffuse Optical Tomography (TR-DOT) was employed in this study along with electromyography. TR-DOT provides information on the oxygenation condition in the forearm muscles that are loaded by grip exercise. Electromyography provides more direct indexes on the muscle conditions under test. However, it should be noted that the observable electromyography signals are supplied mainly by the surface muscles of the forearm which are not directly concerned with grip exercise.

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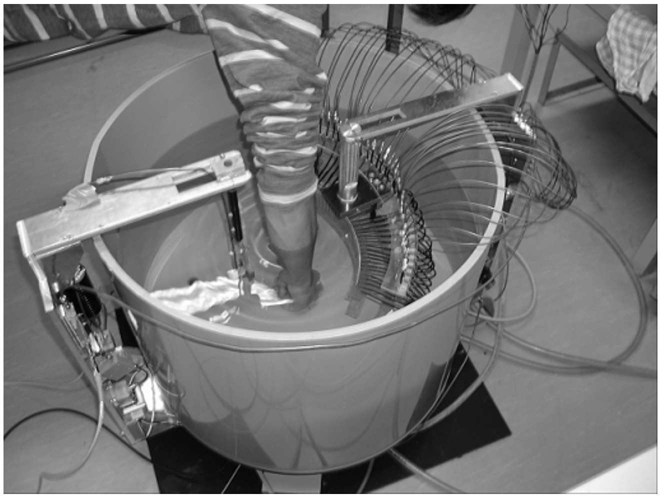
II. Muscle Activity Imaging by CP-MCT

A. Experimental Setup

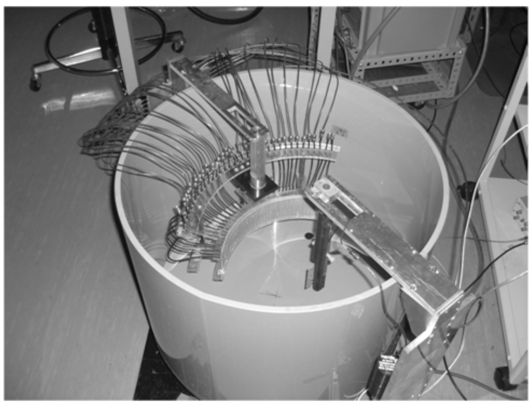
We developed two prototype models of CP-MCT so far as shown in Fig. 1. Type-I was designed for noninvasive imaging of brain functions in a human head. This model utilizes the chirp signal from 1 to 2 GHz and measures the biological object up to 200 mm in diameter. As shown in Fig. 1(a), heads are pushed up into bolus saline solution from the bottom of the bolus tank by preventing water leak with a plastic film. According to the computer simulation, it can visualize small temperature change inside of the brain.

Type-II model is used to visualize the muscle functions in the forearm like a manner as shown in Fig. 1(b). Frequency band and sweep time of the chirp pulse signal are 2 to 3 GHz and 20 ms. Fan-beam scanner is consisted of dielectric-loaded waveguide-type transmitting antenna and 31 sandwiched receiving dipole array antennas as shown in Fig. 1(c). It takes approximately five minutes for imaging of a forearm.

(a) CP-MCT Type-I developed for human head imaging



(b) CP-MCT Type-II used for imaging of human arms



(c) Fan-beam scanner of Type-II CP-MCT

Fig. 1 Developed CP-MCT system

B. Numerical Simulation

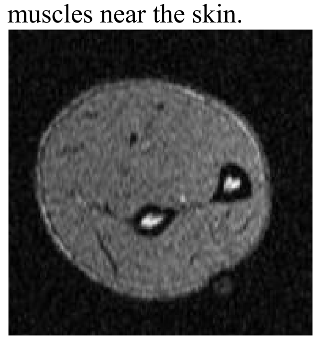
Preceding the actual imaging, FDTD-based simulation was carried out on the forearms and lower legs. Numerical models for FDTD analysis were developed by employing MR data of a subject and permittivity database of human tissues [8]. Those models are two-dimensional and permittivity values at 2.5 GHz were used for this computation, where 2.5 GHz is the center frequency of the input chirp pulse signal. According to our experience, FDTD computation in which dispersion in permittivity of biological tissues is taken into consideration does not bring significant change in the reconstructed image of CP-MCT. Therefore, the numerical simulation was done at the constant frequency of 2.5 GHz.

Figure 2(a) and (b) are MR images of the subjects who served to this study. Computed results are given in Fig. 2(c) to Fig. 2(f). Figure 2(c) and (e) were obtained when bolus solution was pure water, whereas Fig. 2(d) and (f) were obtained by using bolus saline solution whose salt concentration was 0.5 %. Due to the residual scattering waves around bones, the computed images are a bit blurred. It will be concluded that morphological information is derived also from those CP-MCT images although such information is not the final goal of this study.

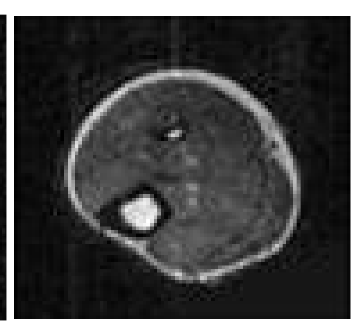
C. Visualization of Exercise-Based Muscle Activity

As shown in Fig. 1(b), each subject holds his arm downward perpendicularly to the measurement plane from top of system and grasps a rubber ball firmly in the bolus saline solution. Concentration of the bolus saline solution is 0.54% and the temperature is approximately 25 ºC. Muscle activity imaging is completed by successive three measurements. The first imaging is done without placing anything in the measurement region to obtain the background projection data of CP-MCT. The second imaging is done by placing a forearm before loading. After loading the forearm by gripping and grasping, the third imaging is carried out. The load is given to the muscles by a gripper for one minute preceding the third measurement and by grasping a rubber ball during measurement for about 4 minutes in saline solution bolus by keeping the arm in the measurement position. The grip power is almost equal to 20 kilogram. This is equivalent to the power supplied by a hand-gripper used in TR-DOT. Graphical explanation of the loading method is given in Table 1.

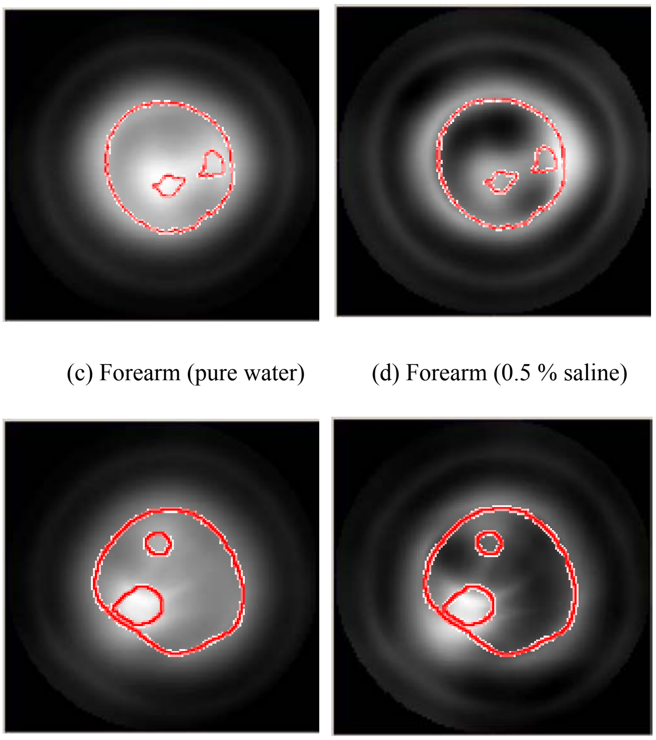
Figure 3(a), (b) are the pre-processed images obtained before- and after-exercise. All figures in Fig. 3 were magnified to examine the gray level change precisely. However, the close resemblance between Fig. 2(c) and Fig. 3(a) was at least confirmed. Dotted curves represent the outer shapes of the forearm and bones obtained from MR images before or during exercise (ball grasping). The cross sectional shape of the arm changes according to contraction of the forearm muscles. To suppress the influence of this deformation onto subtraction between Fig. 3(a) and Fig. 3(b), Fig. 3(b) is transformed into Fig. 3(c) by applying affine transformation-based registration program provided by MATLAB. In the registration process, five reference points were chosen, that is, three marked points on the skin surface and two points corresponding to the center of gravity of the bones. Finally, we get Fig. 3(d) by subtracting Fig. 3(a) from Fig. 3(c). Since these images are tomograms, the subtracted image shows the relative change in the gray level at the cross section of the forearm. It is evident that attenuation change is different between the inner muscles around bones and outer muscles near the skin.



(a) Forearm



(b) Leg

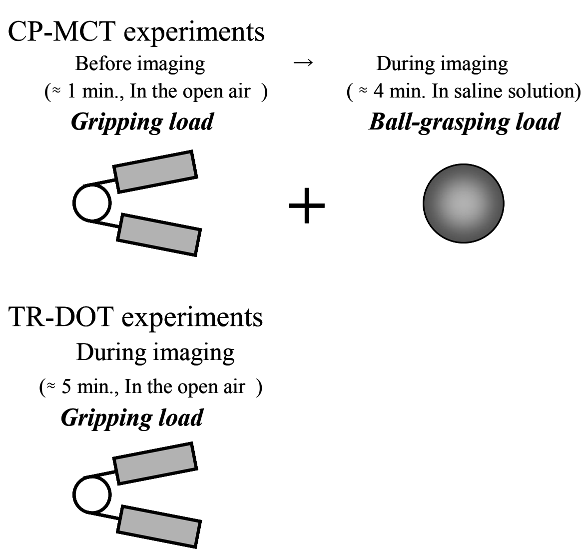


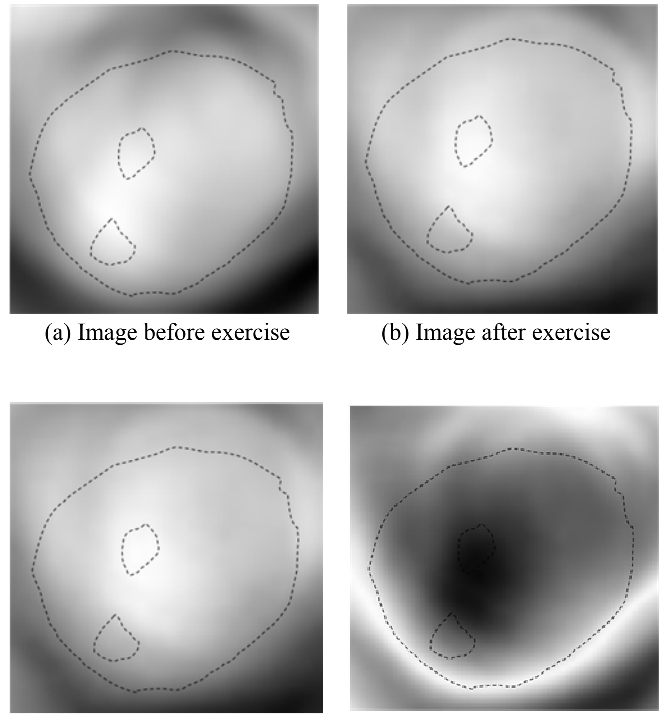
(c) Forearm (pure water) (d) Forearm (0.5 % saline)

(e) Leg (pure water) (f) Leg (0.5 % saline)

Fig. 2 MR image-based numerical simulation in CP-MCT imaging

Table 1 Loading method to forearms





(a) Image before exercise (b) Image after exercise

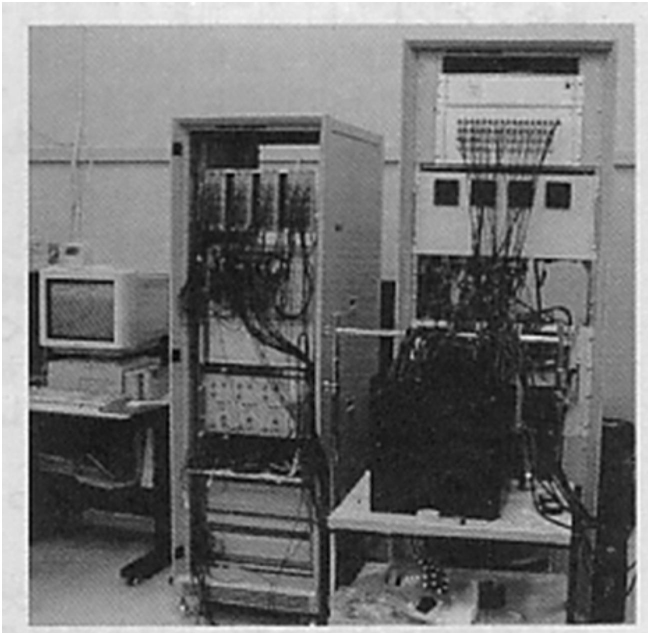
(c) Image after exercise (after registration) (d) Subtracted image

Fig. 3 Gray level change in forearm image of CP-MCT due to exercise

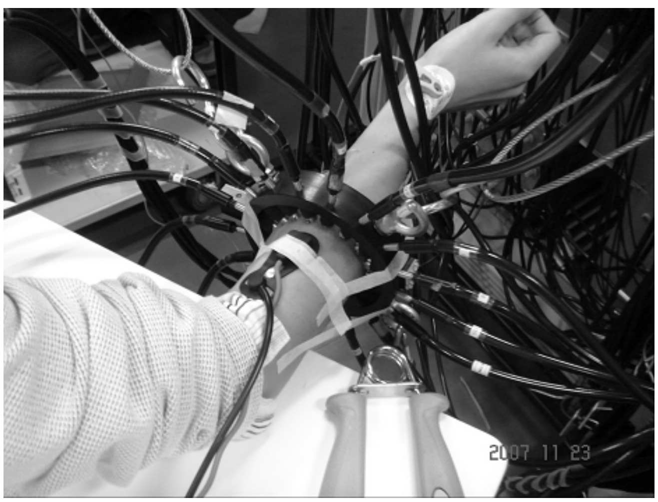
III. Oxygen Metabolism Imaging by TR-DOT

A. Experimental Setup

Figure 4(a) is 16-channel TR-DOT system developed at National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan. Figure 4(b) shows the aspect of experiment which measures forearm muscle activity. The system is consisted of time-correlated single photon counting system and three pulsed laser diodes emitting ultra-short light whose pulse widths are approximately 100ps at 759, 799 and 834 nm. At 16 detector positions around the forearm, TR-DOT is able to detect the transmitted lights illuminated at a position out of 16 detector positions. Modified generalized pulse spectrum technique [9] was employed for image reconstruction of TR-DOT.



(a) TR-DOT system



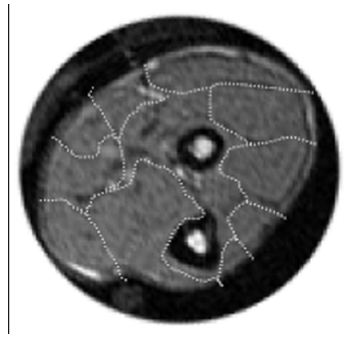
(b) Forearm imaging by TR-DOT

Fig.4 Whole view and experimental view of TR-DOT

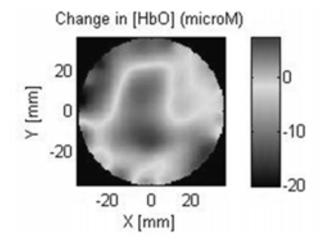
B. *Visualization of Oxygen Metabolism*

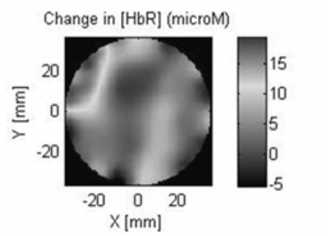
Figure 5(a) to (e) shows the MR image of the forearm and reconstructed TR-DOT images showing changes in the oxy-Hb (b), deoxy-Hb (c), total-Hb concentration (d), and oxygen saturation (e).

The large oxygenation changes are observed in the central region around the bones. It seems that there exists difference in the muscle activity between the center- and outer- regions. It is considered that this change is caused by the activation of the inner muscles.

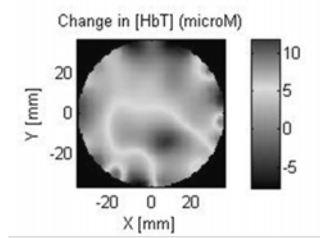


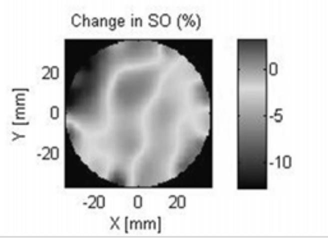
(a) MR image of forearm





(b) Oxi-Hb change (c) Deoxi-Hb change





(d) Total Hb concentration (e) Oxygen saturation

Fig. 5 DOT images during exercise

IV. MUSCLE ACTIVITY BY ELECTROMYOGRAPHY

Muscle activities were recorded and analyzed by means of electromyography over six subjects. The electromyography data were acquired during the optical imaging experiments by TR-DOT [10]. Since the electrodes are pasted onto the skin surface, the recorded activities mainly show the behavior of outer muscles. Judging from two indexes of the mean power frequency (MPF) and average of rectified value (ARV), it is evident that so-called muscle fatigue was produced by gripping or grasping. The muscle fatigue was observed in four cases out of six measurements. However, it is well known also that gripping power is produced by the cooperative works of the inner muscles. The outer muscles are used only for preventing the rotation of wrist joint. Accordingly, electromyography provides almost no information on the gripping power.

V. Discussion

In this study, we have demonstrated that the gray level of CP-MCT image changes differently between the central- and surface- regions of the forearm when the grip load is given.

It is hard to point out the exercise-driven activated region in the forearm muscles by comparing those two images. However, we have demonstrated that the change is visualized by subtracting those two images. According to the experimental results, slight difference was observed between the central- and surface-regions. Similar results were observed in TR-DOT. Judging from the experimental conditions, it is considered that position dependent changes are due to the activation of inner muscles in the forearm.

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