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Calibration of Cross-Sectional Images Measured by an Ultrasound-Based Muscle Evaluation System

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Abstract— **The quantification of muscle volume can be used to estimate muscular strength. Therefore, we developed a flexible measuring system for muscle volume using ultrasonography. In the measuring process, subjects are not required to perform any muscular contraction, so it is completely safe and particularly suitable for elderly people. The ultrasound probe is installed on a mechanical arm, and continuously scans fragmental images along the body surface. The measured images are then composed into a wide area cross-sectional image.**

However, the muscle area measured by our system was slightly smaller than that measured by MRI. because the ultrasound probe contacted the body surface with a little pressure during the measurement. The strain then decreases the total image size and its circumference. This paper introduces our developed system and proposes a new calibration method for the muscle area in the thigh based on its circumference.

I. Introduction

Japanese society has been aging recently, and the issue of bedridden elderly people is becoming serious[1]. Evaluating the Activities of Daily Living (ADL) is very important for preventing people from becoming bedridden. Muscular strength is an index for evaluating ADL. However, it is sometimes risky to measure the muscular strength of elderly people because a voluntary muscular contraction might be a factor of arthritis and osteoarthritis. In particular, we have to pay the closest attention to elderly people who require nursing care.

Previous research attempted to estimate muscular strength based on muscle volume. For example, Katsumata et al.[2] examined the relation between throw speed and the muscle volume of university baseball pitchers. They reported significant correlations between the throw speed and the muscle volume measured by the bioelectrical impedance method. Also, Gadeberg et al.[3] found a correlation between maximal isokinetic muscular strength and the volume of ankle dorsiflexors and plantar flexors. However, the measurement accuracy of the bioelectrical impedance method seemed to be insufficient due to differences of polar contact conditions. MRI and X-ray CT can be used to quantify muscle volume[4],[5], but these devices are not widely available, except in medical institutions. Also, X-ray CT has a serious drawback in that the subjects are exposed to radiation.

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In previous research, we developed a cross-sectional image measurement system using ultrasound to evaluate muscle volume[6]−[8]. This system used ultrasound probes and measured fragmental images of the extremities from several angles. These images were then composed into the whole cross-sectional image. We conducted experiments to confirm the system. In the experiments, we measured the muscle volume of thighs of many subjects and reported the change of muscle volume with aging[8].

However, this system had several problems to be solved for the elderly and the disabled. First, the subject had to insert his/her extremity into a water tank to measure the ultrasound image, sometimes requiring the subject to assume an unnatural posture. Second, the cross-sectional image processing only selected the brightest pixels from the layered fragmental images. Therefore, we sometimes had difficulty tracing tissue boundaries in the composite image.

To overcome these problems, we developed a new flexible muscle volume evaluation system[9]. In the system, an ultrasound probe is installed on the tip of a mechanical arm and flexibly scans along the body surface. The muscle volume of the elderly and disabled can be measured in arbitrary postures such as sleeping or sitting. Also, high-quality images can be expected because the spatial compound method is applied to the cross-sectional image during image processing[10]−[12].

The only problem is that the muscle area measured by our system was slightly smaller than that measured by MRI bacause the ultrasound probe pressed slightly against the body surface during the measurement, and the resulting strain decreased the total image size and circumference. This paper introduces our developed system and proposes a new calibration method for thigh muscle areas based on the thigh circumference.

II. System composition

Figure. 1 presents an overview of measurement by the developed system. The ultrasound probe is attached to the tip of the mechanical arm and can be moved flexibly along the body surface. This system is lightweight and compact, so we can carry it with our laptop computer.

The system consists of two parts, a measurement unit that includes the ultrasound system and the mechanical arm and image composition software to compose a cross-sectional image from fragmental images.

A. Measurement unit

The mechanical arm is made of stainless steel and has four degrees of freedom. Each joint has a ball bearing, so

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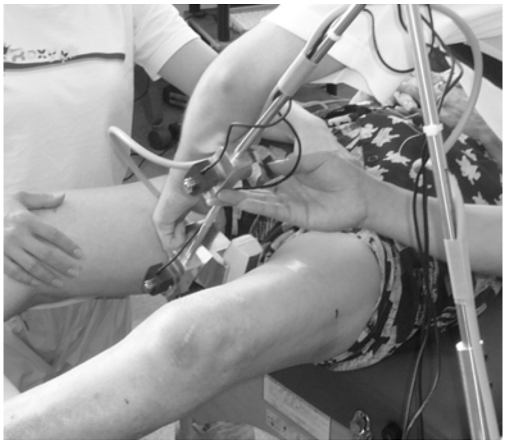

Fig. 1. Overview of the measurement.

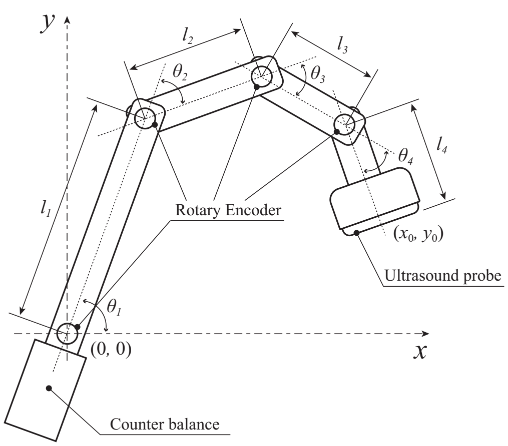

Fig. 2. Composition of the mechanical arm.

that it can be rotate very smoothly. The mechanical system weights 8.0 [kg] (including a counter balance). The counter balance is installed in the first link. The length of each link can be adjusted, the first link from 270 to 450 [mm], the second link from 105 to 373 [mm], and the third link from 75 to 147 [mm]. The fourth link is fixed at 65 [mm]. As illustrated in Fig. 2, the coordinate system is defined such that the joint axis of the first link is the origin (0, 0), and the counterclockwise direction is forward.

The ultrasound imaging device (HS-1500, Honda Electronics Co., Ltd.) is used to measure the fragmental images. The ultrasound probe (HLS-338M) is a linear model with a 5.0 [MHz] central frequency and an 80 [mm] measurement width. Four high-resolution 2000 [P/R] encoders (UN-2000, Mutoh Engineering, Inc.) are used to measure the joint angles. The fragmental images and the joint angles are transferred into a personal computer via the image capture board (NI PCI-1411, National Instruments) and a counter board (NI PCI-6602, National Instruments).

B. *Image composition software*

We can observe tissue boundaries in detail because the image contrast was considerably improved. Our system adopts the spatial compound method in order to compose a clear cross-sectional image. The current system should be able to observe individual muscles, such as extensors, and flexors, although this was impossible for our previous system.

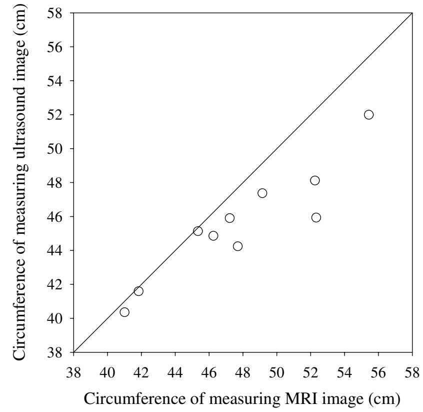

Fig. 4. Error of the thigh circumference.

The position of the probe (x_0, y_0) is calculated based on the joint angles obtained using the encoders in each joint (Fig. 2).

$$\begin{aligned} x_0 &= l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2) \\ &+ l_3 \cos(\theta_1 + \theta_2 + \theta_3) + l_4 \cos(\theta_1 + \theta_2 + \theta_3 + \theta_4) \\ y_0 &= l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2) \\ &+ l_3 \sin(\theta_1 + \theta_2 + \theta_3) + l_4 \sin(\theta_1 + \theta_2 + \theta_3 + \theta_4) \end{aligned}$$

Here, $\theta_1, \theta_2, \theta_3, \theta_4, l_1, l_2, l_3$, and l_4 are the joint angles and the link lengths as illustrated in Fig. 2. Parameters θ_2, θ_3, and θ_4 are defined as the relative angles between two links, but θ_1 is defined as the angle from the x-axis; l_4 includes the probe length.

III. Experiments

A. *Measurement and image composition accuracy*

Excellent accuracy of measurement accuracy and evaluation of the image composition was sconfirmed in our previous study[9].

B. *Validity of the cross-sectional image*

We conducted an experiment to compare the acquired images with MRI images in order to examine the validity of the cross-sectional images. We measured the thigh at 50% of the length from trochanter major. The measurement was performed in the dorsal position, and the images were measured from the same subject and part. The subjects were six men and four women.

Figure. 3 presents an example of the cross-sectional image measured by our system and by an MRI system. We can distinguish the fat, muscle, and bone in the images from each system. Figure. 4 plots the circumference measured from ultrasound and MRI images. In many subjects, ultrasound

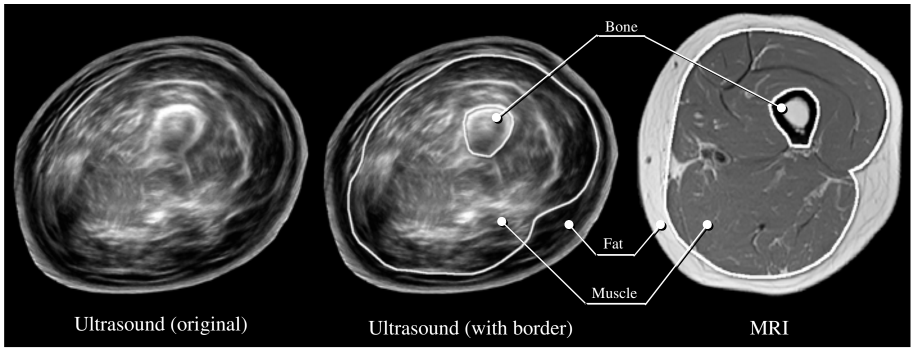

Fig. 3. Cross-sectional images of the quadriceps femoris muscle.

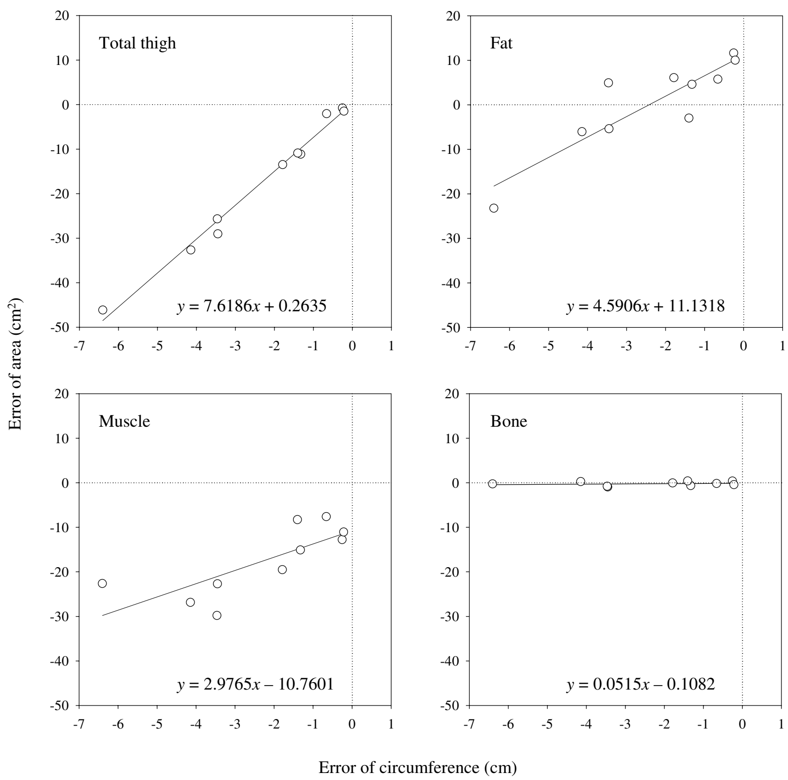

Fig. 5. Correlations between error of the circumference and each tissue area.

measurements were smaller than MRI measurements because the ultrasound probe applied a little pressure to the body surface when we measured the cross-sectional image using this system. The strain tends to decrease the total image size and circumference. Therefore, we need to develop a new method for calibration our system and MRI.

Figure. 5 depicts correlation diagrams between the circumference error and tissue area error. These errors are calculated from images of MRI and our system. The regression functions are also described in each diagram. We can observe a high correlation in the total thigh and fat areas. Therefore, we proposed the following calibration function for the muscle area.

$$\begin{aligned} C_m &= C_t - (C_f + M_b) \\ &= M_t - 7.6186 \times D_c - 0.2635 \\ &\quad -(M_f - 4.5906 \times D_c - 11.1318 + M_b) \\ &= M_t - M_f - M_b - 3.028 \times D_c + 10.8683 \end{aligned}$$

Here, C_t, C_f, C_m, represent the correction areas of the total thigh, fat, and muscles. Similarly, M_t, M_f, M_b indicate the measured areas of the total thigh, fat, and bone, and D_c is the circumference error. The coefficients in the equation are derived from the regression function in Fig. 5.

The muscle area was corrected by this function. Figure. 6 depicts a correlation diagram between the correction area

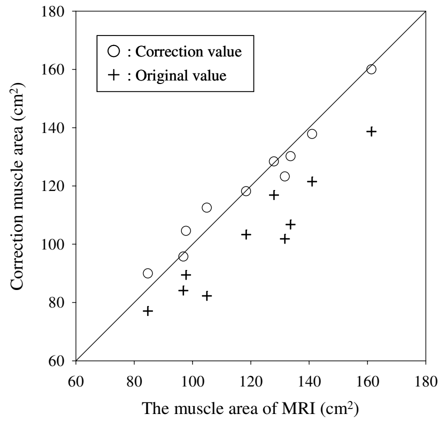

Fig. 6. Correlations between the correction and MRI area in the muscle.

and MRI area. The correlation coefficient was 0.983 with a significance level of 1%.

Next, we examined the accuracy of the measured areas dividing the extensor and flexor muscles in the thigh. Both our system and MRI successfully separated the muscle areas from the cross-sectional image; the images were the same in the above experiment. The separated muscle was subdivided into the extensor and flexor muscles.

Figure. 7 presents the corrected area of the extensor and flexor muscles. The correlation coefficients were 0.968 and 0.988, respectively with a significance level of 1%.

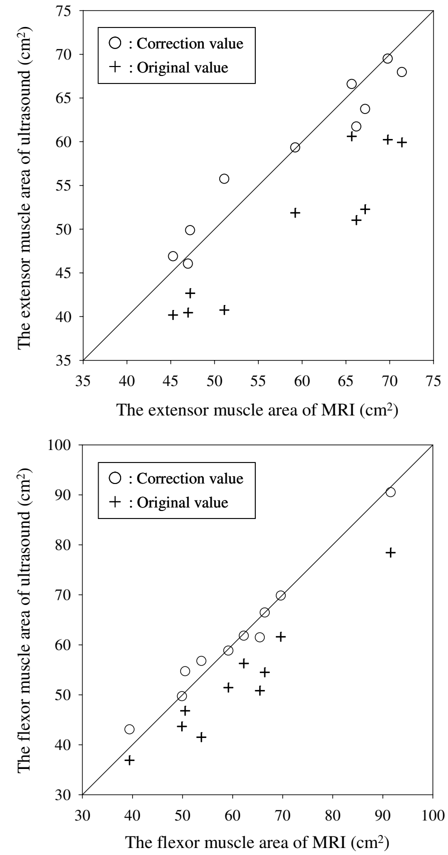

Fig. 7. The extensor and flexor muscle area value.

IV. Conclusion

This paper introduced a muscle-volume measuring system using ultrasound. In this system, the ultrasound probe was installed on the tip of a mechanical arm and scanned the body surface flexibly. In particular, muscle volume of elderly people and the disabled could be measured in arbitrary postures such as sleeping or sitting because the flexible mechanical arm considerably increased the measurement areas and shapes.

Experiments confirmed the measurement performance of the developed system. Also, we proposed a new method to calibrate the muscle area based on the circumference of the extremities.

The system could be expected to be used for sports training evaluations and the rehabilitation of elderly people.

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