Evaluation of Lower Leg Swelling Using EMG Measured with Voltage Divider

Akito Murai, Yusuke Sakaue-*IEEE Member*, and Masaaki Makikawa, *IEEE Member*

Abstract— **The purpose of this study is to evaluate the lower leg swelling using EMG measured with our new voltage divider technology, by which the internal impedance of lower leg can be estimated. The amplitude of EMG measured without voltage divider was compared to it with voltage divider. Eleven healthy subjects (24.3±5.1 y.o.) participated in this study. Six female (swelling group) were asked to work at desk for six hours, and five male (control group) were asked to work a regular day. The internal impedance was calculated and calf circumference was measured before and after desk work. Results show that internal impedance in swelling group significantly decreased with increase in calf circumference, and our new evaluation method was proved to be effective for the evaluation of lower leg swelling.**

I. Introduction

Lower leg swelling is occurred by the increase of extracellular fluid in lower leg. The extracellular fluid circulates around the body by blood and lymph flow, and both fluid circulations are generated by muscle and heart pump activities. The reduction of these pump activities cause poor circulation of extracellular fluid, and increase the extracellular fluid in lower leg. Therefore, lower leg swelling is caused by the lack of exercise and muscle atrophy. Lower leg swelling is painful and uncomfortable and moreover it increases the risk of blood-flow abnormalities. Some prevention methods of leg swelling were attempted using compression stockings, leg exercise and flooring conditions [1-3].

Typically, lower leg swelling is evaluated by measuring the calf circumference using a tape measure [4]. The lower leg swelling is easily measured by this method, but it involves large measurement errors. Bioelectrical impedance analysis (BIA) is also used for evaluating lower leg swelling [5]. In this method, the bioelectrical impedance is measured using high frequency AC current (more than 100 kHz) passing through human body [6]. Extracellular fluid volume, muscle mass and adipose mass can be calculated from this bioelectrical impedance, and it is possible to quantitatively evaluate the lower leg swelling. The reason why low frequency AC current is not used in BIA is that low frequency current has risks of electrical shock and pacemaker malfunction.

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Recently, we have developed a new signal source estimation method utilizing voltage divider technology [7]. In this method, bioelectrical impedance can be estimated from the body surface potential measured with and without a voltage divider. In our study, surface electromyogram (EMG) of lower extremity was measured as body surface potential. The detail of our measurement theory is described in section II.

Surface EMG has no risk of electrical shock and pacemaker malfunction different from BIA. Surface EMG is non-invasive, and it is widely used to evaluate muscle activities in sports, rehabilitation and bioengineering field. Frequency band of EMG is low (0.005-0.5 kHz) compared to AC current used in BIA. Low frequency signal flows through only extracellular fluid, and hence it may become possible to evaluate the lower leg swelling more sensitively.

The purpose of this study is to evaluate the lower leg swelling using EMG measured with our new voltage divider technology. The amplitude of EMG without voltage divider was compared to it with voltage divider for calculating bioelectrical impedance of lower leg. Experiments were carried out to measure changes in bioelectrical impedance of lower leg before and after lower leg swelling.

II. Theory

Measurement of electrical potential of biosignal inside human body using surface electrode is popular in biomedical engineering. In measurement of biosignal by surface electrode with single-lead amplifier, human body can be replaced by an electrical circuit consisting of a signal source and synthetic impedance inside body [7]. In this study, skin surface EMG was measured using bipolar-lead method.

Fig. 1 shows an electrical model of our measuring system. The muscle is replaced as a signal source of potential V_S, and soft tissues inside body are replaced two synthetic impedance R_{b1}, and R_{b2} to each electrode. The additional resistance R_g was set between positive and negative input through a mechanical switch. This additional resistance R_g and internal impedance R_{b1}, and R_{b2} make a voltage divider, and it attenuates signal source potential at each electrode.

Because input resistance R_{in} of the amplifier is very large (10TΩ), the signal source potential is not attenuated when the additional resistance is switched to be unconnected. Then, the output potential V_{out} is the same as V_S shown by (1), if the gain

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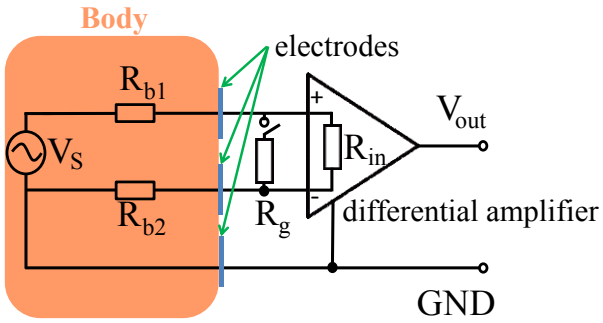

V_S : Signal potentials inside the body
R_{b1} , R_{b2} : Synthetic impedance between electrode and signal source
R_g : Additional resistance
R_{in} : Input resistance of differential amplifier

Figure 1. Model of our measurement system.

of differential amplifier is 1.0. The signal source potential is attenuated when additional resistance is connected, the output potential V'_{out} is calculated by (2). Then, the attenuation rate AR is calculated by (3). Equation (4) is satisfied when AR is 50%, and it is possible to estimate the total value of R_{b1} and R_{b2} in this model. We define the total value of R_{b1} and R_{b2} as internal soft tissue impedance in this study.

$$V_{out} = V_S . \tag{1}$$

$$V'_{out} = \frac{R_g}{R_{b1} + R_{b2} + R_g} V_S . \tag{2}$$

$$AR = \left(1 - \frac{V'_{out}}{V_{out}}\right) \times 100 . \tag{3}$$

$$R_g = R_{b1} + R_{b2} . \tag{4}$$

III. Method

A. Subjects

Eleven healthy subjects (24.3±5.1 y.o.) including six female and five male with no lower extremity problems history participated in this study. Six female subjects were classified into swelling group for convenience, and five male subjects were classified into control group, because female is easily suffered from low leg swelling. Subjects of swelling group were asked to work at desk with their high heels for more than six hours to elicit lower leg swelling. Stockings, long socks or tights are said to assist blood flow, and are effective to reduce the lower leg swelling. Therefore, they were not allowed to wear them. Subjects of control group were asked to work a regular day. They also were asked to work at desk, but allowed walking around college unlike swelling group. All subjects were fully informed the aims and the protocol of this experiment, and they accepted these informed consent.

B. Measurement

The surface EMG was measured for 200 s before and after the desk work, and was stored in PC. Ten additional

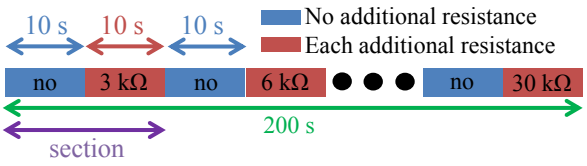

Figure 2. Procedure of switching additional resistances.

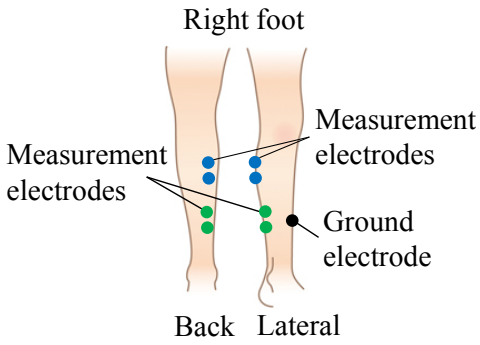

Figure 3. Procedure of switching additional resistances.

resistances (3, 6, 9, 12, 14, 16, 20, 24, 27, 30 kΩ) were set between positive and negative input through a mechanical switch, which connected on each additional resistance and off every 10 s. Fig. 2 shows the switching procedure of additional resistances. Subjects were asked to sit with their calf rising and to hold their ankle joint to 30 degree during EMG measurement. The total gain of the amplifier with high-pass filter of 10 Hz was 78 dB, and the sampling frequency was 1,000 Hz. Calf circumference was measured using a tape measure before and after the experience.

Surface EMG of gastrocnemius was measured at two positions in this experiment, i.e. two pairs of electrodes with a radius of 9 mm were set on the muscle belly of right gastrocnemius and the bottom of this muscle without space between two electrodes. The distance between two electrodes of each pair was 18 mm. Ground electrode was set on right tibia. Before attaching electrodes, sebum and grime were removed using alcohol swab and polish. Fig. 3 shows the scheme of positioning of electrodes in this experiment.

C. Data analysis

Artifacts contaminated in measurement data were first eliminated by digital band-pass filter of 15-500 Hz. Next, absolute values of EMG potentials were calculated at each sampling time. Then, these calculated values were separated into ten sections of 20 s. In each 20 s, average values from 3 to 8 s were chosen as V_{out} and those from 13 to 18 s were chosen as V'_{out}. AR values were calculated at each section using (3). The additional resistance which attenuates the signal source potential to 50% was calculated by logarithmic approximation of AR-R_g relationship, and the internal impedance R_b calculated by (4) is satisfied as the internal impedance when AR is 50%, and the internal impedance R_b (=R_{b1}+R_{b2}) were calculated using (4). This estimated internal impedance R_b and the measured calf circumference before and after the desk work were compared statically by t-test ($p<0.05$).

IV. Result

A. Swelling group

Fig. 4 shows the change in average calf circumference of swelling group before and after the desk work. As shown in this figure, average calf circumference increased from 33.3 cm to 34.3 cm, but there existed no significance. Fig. 5 shows the change in average internal impedance of swelling group before and after the desk work. As shown in this figure, this average internal impedance at muscle belly decreased from 12.6 kΩ to 5.1 kΩ, and there existed statistical significance.

The average internal impedance at the bottom of gastrocnemius decreased from 14.6 kΩ to 10.0 kΩ, but there existed no significance. The decrease of average internal impedance at muscle belly was 7.5 kΩ and bottom of gastrocnemius was 4.6 kΩ.

B. Control group

Fig. 6 shows the change in average calf circumference in control group. The average calf circumference increased from 37.4 cm to 37.6 cm, but there existed no significance. Fig. 7 shows the change in average internal impedance of control group. The average internal impedance at muscle belly decreased from 14.0 kΩ to 9.1 kΩ, but there existed no significance. The average internal impedance at the bottom of gastrocnemius decreased from 11.5 kΩ to 8.3 kΩ, but there existed no significance. The decrease of average internal impedance at muscle belly was 4.9 kΩ and bottom of gastrocnemius was 3.2 kΩ.

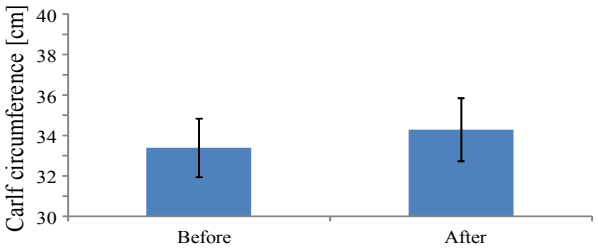

Figure 4. Change in average calf circumference of swelling group before and after the desk work.

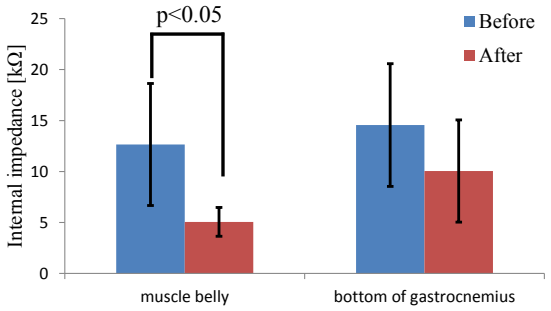

Figure 5. Change in average internal impedance of swelling group before and after the desk work.

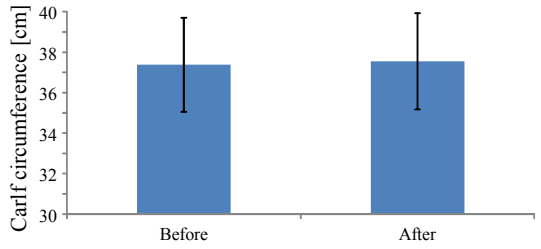

Figure 6. Change in average calf circumference of s control group before and after the desk work.

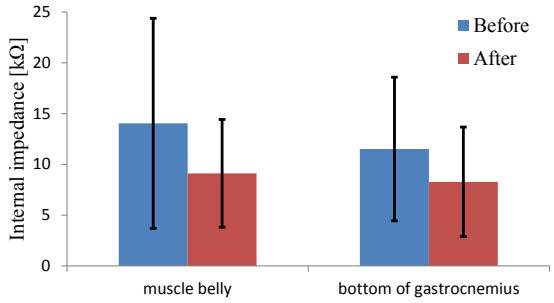

Figure 7. Change in average internal impedance of control group before and after the desk work..

C. All subjects

Fig. 8 shows the relationship between internal impedance change and calf circumference change of all subjects. As shown in this figure, the internal impedance decreased, and calf circumference showed the same value or increased in all subjects. There were a few subjects whose internal impedance decreased in spite of almost same value in calf circumference. The changes of internal impedance and calf circumference in swelling group were larger than those of control group.

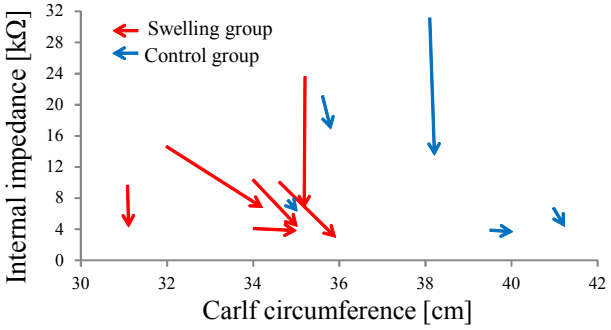

Figure 8. Relation between internal impedance and calf circumference of all subjects

V. Discussion

Lower leg swelling is occurred by the increase in extracellular fluid of lower leg. As shown in Fig. 4, the calf circumference increased by six hour work at the desk. This result suggests that desk work causes the loss of muscle pump function which circulates extracellular fluid. As shown in Fig. 6, the calf circumference vanishingly increased, and this result suggests that their muscle pump function would be stimulated by daytime activities.

As shown in Fig. 5, the internal impedance decreased significantly, and this result is consistent with previous studies that bioelectrical impedance estimated using BIA decreased by lower leg swelling [5].

The internal impedance in control group decreased in spite of almost no change in calf circumference. It is said that the bioelectrical impedance of lower leg in the evening is lower than morning because a portion of the lower leg extracellular fluid is moved from the legs through the abdomen, and redistributed [8]. Results indicate that this difference of internal impedance would be measured using our proposed measurement method.

Decrease of internal impedance in swelling group is larger than that in control group. This result suggests that long time desk work causes more extracellular fluid in lower leg of swelling group by loss of muscle pump function.

As shown in Fig. 5 and 7, the decrease of internal impedance at muscle belly is larger than that at the bottom of gastrocnemius. Therefore, it is suggested that more extracellular fluid stores between muscle belly of gastrocnemius than at the bottom of gastrocnemius.

As shown in Fig. 8, the internal impedance decreased, and calf circumference showed almost same value or increased in all subjects. There were a few subjects whose internal impedance decreased in spite of the same value in calf circumference. Hence, it is suggested that the internal impedance decreased in a day in spite of the fact that calf circumference remains unchanged. It may be possible that measurement of extracellular fluid change which does not influence on circumference using this method.

VI. Conclusion

The lower leg swelling increases the extracellular fluid and decreases the bioelectrical impedance of lower leg. Here proposed a new evaluation method of lower leg swelling from EMG measurement with our new voltage divider technology.

In this study, the effectiveness of this method was verified by estimating the internal impedance before and after the long time desk work. The internal impedance estimated by this method decreased significantly by lower leg swelling. These results are thought to prove that our method is effective in the evaluation of lower leg swelling. Moreover, the internal impedance in EMG with band frequency from 15 Hz to 500 Hz was estimated by our new method. It may be possible that internal capacitance included in internal impedance is estimated from internal impedance which calculated at various frequency bands. The lower leg swelling would be evaluated more precision by estimating both internal resistance and capacitance.

There exist many reduction methods of leg swelling, i.e. compression stockings, leg movements and flooring conditions [1-3]. Our proposed measurement method may contribute to find out new reduction methods of lower leg swelling without risk of pacemaker malfunction and the electrification different from BIA.

The calf circumference was measured simultaneously as the reference of lower leg swellings in our study. However, it is suggested that internal impedance decreased in spite of almost same value in calf circumference. This result suggests it is necessary to measure the changes of extracellular fluid using BIA. The future task is to verify the utility of our method for measurement of extracellular fluid changes by comparing the value which is estimated by BIA.

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