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Short Communication

A Portable Apparatus for Monitoring Leg Swelling by Bioelectrical Impedance Measurement

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Measurement of leg swelling is widely used for the evaluation of the load in standing work. Measuring the leg circumference with a tape measure and the leg volume in a water tank were methods often used to measure the level of leg swelling[1]. These methods, however, were not suitable to apply to field studies because they take time and require support staff when taking measurements.

We studied the bioelectrical impedance measuring method and found it much more sensitive than the leg circumference and leg volume measuring methods[2]. This method was considered to be useful for field studies because it measures leg volume electrically and can therefore measure automatically without disturbing work. For this purpose, we developed a new portable apparatus to monitor leg swelling by an impedance method. In this paper, we give an outline of the apparatus and a sample of data related to its application.

Outline of the Apparatus

The block diagram of the apparatus is shown in Fig. 1. This apparatus measures leg impedance by a four-electrode method. The measured impedance is displayed on the LCD (liquid crystal display) and can be read directly in ohms. The displayed value is the average for 1/3 sec, and is updated automatically. The measuring frequency and current are fixed at 5KHz and 200 μA_{rms} (root mean square), respectively. The range of measurement is 0.1 to 199.9 ohm at a resolution of 0.1 ohm. The dimensions of the apparatus are $13 \times 9 \times 4$ cm and the weight is 330 g (including battery). The apparatus can operate continuously for more than 13 hr on battery power.

The leg swelling is detected as an impedance reduction that is brought about by the leg volume increase with body fluid pooling. The impedance is in precisely inverse proportion to the leg volume. When measuring the impedance by the four-electrode method, two current electrodes supply a constant alternating current and two detecting electrodes detect the voltage difference corresponding to the impedance. The electromyographic potential may interfere with the measurement if the detecting electrodes are fixed on the leg muscles. The measuring current should be high enough to avoid interference, but low enough to avoid electric shock. We applied the current at 200 μA_{rms}. It causes a 4 to 14 mV_{rms} voltage difference at the detecting electrodes assuming that the leg impedance is 20 to 80 ohm. It is high enough compared with the electromyographic potential in the resting condition (about 50 μV_{rms} at most).

The tissue impedance depends on the measuring frequency because of the electrical capacity of the cell membrane. According to a bioelectrical model of the tissue[4], it consists of two electrical components: (1) intracellular fluid and cell membrane, and (2) extracellular fluid. To monitor the dynamics of the extracellular fluid that relates to the tissue swelling by the impedance method, measurement should be done at low frequency, as the component of the intracellular fluid and cell membrane can be neglected. According to the results of our previous study, the impedance at low frequency is theoretically about four times more sensitive in detecting changes in leg swelling than that at high frequency[2]. A direct current or alternating current at too low a frequency is, however, not recommended because of the electrical damage caused by electrolysis and high skin impedance. Considering these factors, we applied measuring frequency at 5 KHz.

To maintain precision in measuring, the impedance of the electrodes for the apparatus must be lower than 4 Kohm. A disposable Ag/AgCl electrode with electrolytic paste is recommended because of its low skin impedance and the stability of the fixation. The electrodes are fixed on the medial side of the leg as shown in Fig. 1. The two detecting electrodes are fixed at proximal and distal points about 7.5 cm from the thickest part of the calf. The current electrodes should be fixed as far apart from the detecting electrodes as

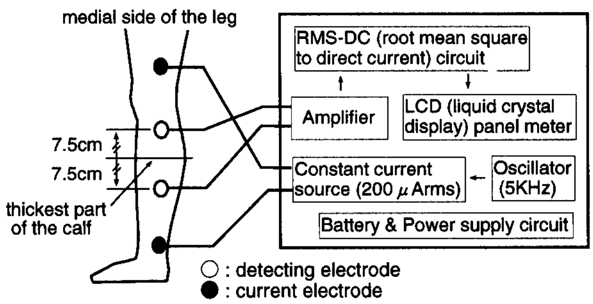

Fig. 1. Block diagram of the apparatus and the electrode location.

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possible to reduce the effect of skin impedance. We therefore fixed the proximal and distal electrodes at the thigh and ankle.

When using the apparatus, the subject carries it on a waist belt. To take a measurement, the subject turns on the power, waits for a second to stabilize the apparatus, and reads the impedance. It can be read immediately when the power is on continuously. The measured values are easily affected by leg conditions such as leg posture and muscle contractions. Subjects have to relax and keep their legs in the same position while measuring, although it only takes a few seconds.

Example of Application

The leg swelling of a nurse (male, 25 yrs.) was measured during his work with our apparatus. He assisted surgery in the operating room and visited the bedside to check on the condition of patients before operations. He was almost always standing while working. The impedance in his right lower leg and subjective complaint of leg dullness were recorded every 30 and 60 min, respectively. Leg dullness was scored as at one of five levels (1: lowest, 5: highest). Power to the apparatus was turned on only when reading the impedance.

The results are shown in Fig. 2. Regression lines are also indicated in the figure to show the linear trend of the data. The impedance was reduced with time, indicating an increase in leg swelling. The subjective complaint of leg dullness was also increased. He took a rest from 14:30 to 15:10 in a sitting posture, but it was not sufficient for him to recover from the leg swelling and the subjective complaints.

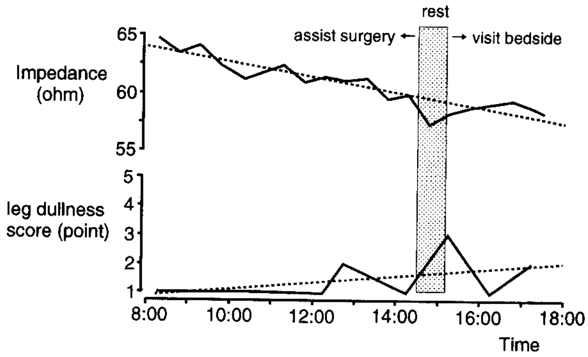

Fig. 2. Changes in lower leg impedance and leg dullness in a male nurse who worked in the operating room and at the bedside. Dotted lines indicate the regression lines.

Discussion

The leg swelling level was affected by various factors such as the muscle pump excited by the intermittent muscle contraction, hydrostatic pressure, inhibition of the circulation by the seat pressure while sitting, and high interstitial pressure caused by continuous muscle contraction[4,5]. During the standing work without changing posture, the level of leg swelling increases simply according to the number of working hours[2]. In most working conditions, however, workers often change their working posture and leg activities as the job demands, and this may cause various changes in leg swelling. The leg swelling should therefore be measured repeatedly to precisely evaluate the standing work load. Our apparatus is convenient for this purpose as it takes only a short time to take measurements and can avoid disturbing work.

For field applications, it is necessary to establish a technique to cancel the effect of the measuring postures. The baseline impedance value depends on the measuring posture. The value changes with the leg volume that mainly depends on the level of ankle joint bending and venous pooling[6]. It takes about 2 min to fill the blood vessels and for impedance to settle when subjects change their posture[5]. Consequently it is also necessary to minimize posture changes to take measurements, and when workers work continuously both standing and sitting, it is better to have two measuring postures. To cancel the baseline difference between postures, many mathematical techniques may be useful, such as using the mean value for the two groups, the mean values corrected by the measuring time, and calibrated values in two postures collected before and/or after the survey. Further research is required to find out the best cancelling method.

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