1 Introduction

The methods which the following features have been needed for measurement of biodynamics in sports training and related fields. The measurement must be as nonrestrictive as possible and easily taken. The information on movement must be obtained instantly from the measurement results. The measurement system must also be low cost. In accordance with these features, some kinds of equipment have been employed including the goniometer, the electromyograph, the camera and the video camera. Each piece of equipment has unique advantages, but there are problems in relation to each piece of equipment. Some examples are as follows (Adrian and Cooper, 1989; Elliott, 1988):

(a) The goniometer is not suitable for complex or fast movement, it is not durable and it restricts the movement of the subject, because it has a structure of mechanical parts.

(b) It is difficult for the results of the electromyograph to be correlated to kinematic and kinetic parameters.

(c) The data from a camera cannot be processed quickly, because it is necessary to develop film.

(d) In analysing video information, a video analyser, which is high in cost and not simple, is needed. The measurement space of the video camera is limited.

Therefore we are proposing a new measurement method using human-limb impedance. This idea originates from the following: first, there is the experimental fact that human movement causes impedance changes; and secondly, the impedance method satisfies the above-mentioned measurement conditions and is applicable to daily use. This method uses the human body itself as a part of the sensor, and the change of bioelectrical resistance is measured during human movement. This method has the following characteristics: (a) it does not have a spatial and temporal limitation for measurement; (b) the subject is scarcely restricted in movement; (c) the data processing can be handled easily and quickly; (d) impedance waveforms inherently show magnitude, form and stability of movement.

2 Materials and methods

2.1 Principle of biodynamic analysis using human-limb impedance

Biodynamics is characterised by magnitude of movement, form of movement and stability of movement. A summary of the magnitude of movement and the form of
movement is defined as the movement pattern. It is very important to evaluate these exactly. We propose to analyse movement biodynamics using impedance characteristics, because human-limb impedance varies with human movement. We try to evaluate the movement pattern using the pattern of the impedance waveform (i.e., the impedance pattern), and the stability of movement using the reproducibility of the impedance waveform. The human limb has a complicated structure that consists of bone, muscle, fat, blood and skin. A constant current of frequency 50 kHz flows almost throughout the tissues of muscle and blood, whose resistivity is lower than the others’ (GEDDES and BAKER, 1989). The human limb is approximated by the parallel conductivity which consists of tissues of muscle and blood. The changes of SI mean the changes in a sectional area of muscular tissue; \( S_m \), and the changes of \( V_b \) mean the changes of blood volume in the measured part. Although \( S_b > S_m \), \( V_b \) concerns the change of impedance because \( \sigma_m < \sigma_b \).

This method has the following advantages: it can be used with a telemetry system and does not have a spatial limitation for measurement. The data can be compressed and measured continuously for long periods. The results can be displayed simply. Various analysis methods can be done: superimposed periodic movement is one of the examples. The subject, who puts small electrodes on his body, is scarcely restricted in movement and experiences no mental pressure.

2.2 Measurement device of human-limb impedance

Fig. 1 shows a block diagram of the measurement device of human-limb impedance. The method of impedance measurement uses the four-electrodes technique based on constant current (50 kHz, 500 \( \mu \)A) (GEDDES and BAKER, 1989). The four-electrodes technique is the method where four electrodes are put on in a line, constant current flows through the outside two electrodes (current electrodes, \( I^+ \), \( I^- \)), and the potential difference, which arises between the inside electrodes (potential electrodes \( P^+ \), \( P^- \)), is detected. The measurement device consisted of a generator, a voltage-to-current convertor, a differential amplifier, a multiplier, a low-pass filter and an amplifier.

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Fig. 2 shows the locations of the electrodes. The measured parts were the middle of the upper limb, whose length was 10 cm, with impedance \( Z_1 \); the forearm near the elbow joint, whose impedance is \( Z_2 \); and the forearm near the wrist joint, whose length was 8 cm, with impedance \( Z_3 \) (Fig. 2a). The other measured part was the middle of the forearm, whose length was 8 cm, with impedance \( Z_4 \) (Fig. 2b), where \( H \) was the length between the top of the olecranon and the processus styloideus. \( Z_1 \), \( Z_2 \) and \( Z_3 \) were adopted to show the characteristics of impedance in some parts of the upper limb. Considering these results, \( Z_4 \) was adopted to measure the movements of tennis. Hence, to standardise the measured parts among subjects, the locations of electrodes are shown with \( H \) in Fig. 2b. All electrodes were attached to the outside surface of the upper limb. Ag/AgCl electrodes of 10 mm diameter were used.

2.3 Measurement system and methods

The elbow joint angle \( \beta \) and the wrist joint angle \( \alpha \) were measured with an electrogoniometer. The electromyograph EMG was measured with the method using skin-surface electrodes. Acceleration \( a \) was measured with an acceleration meter using a load cell sensor. The ball velocity in the tennis ground stroke, \( v_{ball} \), was calculated using the time lag between the time when the ball was hit and the time when it had reached a target. These times were determined with a string gauge sensor in the racket and the target. Impedances measured with telemetry and other electrical signals were taken in and analysed with the microcomputer (PC-9801VX; NEC Corp.).