Motion discrimination of throwing a baseball using forearm electrical impedance

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Abstract. The extroversion or hyperextension of elbow joint cause disorders of elbow joint in throwing a baseball. A method, which is easy handling and to measure motion objectively, can be useful for evaluation of throwing motion. We investigated a possibility of motion discrimination of throwing a baseball using electrical impedance method. The parameters of frequency characteristics (Cole-Cole arc) of forearm electrical impedance were measured during four types of throwing a baseball. Multiple discriminant analysis was used and the independent variables were change ratios of 11 parameters of forearm electrical impedance. As results of 120 data with four types of throwing motion in three subjects, hitting ratio was very high and 95.8%. We can expect to discriminate throwing a baseball using multiple discriminant analysis of impedance parameters.

1. Introduction
We have proposed biodynamics analysis using equivalent series resistance of bioelectrical impedance at 50 kHz [1, 2]. We have also developed a measuring system of frequency characteristics of Bioelectrical impedance with high time resolution [3] and showed that a motion discrimination (hitting ratio 95.0%) in the following six motions: palmar flexion, dorsi flexion, ulnar deviation and radial deviation of wrist joint, and pronation and supination of forearm using four parameters of frequency characteristics of forearm electrical impedance [4].

As an application for sports, we are interested in throwing a baseball. The extroversion or hyperextension of elbow joint cause disorders of elbow joint in throwing motion Improvement of throwing motion, which causes less injury, can prevent the disorders [5]. Though a video camera system is needed in order that a quantitative analysis of throwing motion, it is evaluated visually or subjectively using video picture because the video camera system is complicated to set up and high-priced. A method, which is easy handling and to measure motion objectively, could be useful for evaluation of throwing motion. We investigate a possibility of discrimination of throwing a baseball included easily-hurt motion using parameters of frequency characteristics (Cole-Cole arc) of forearm electrical impedance using high time resolution measurement.
2. Materials and methods

2.1. Characteristics of bioelectrical impedance

The frequency locus of bioelectrical impedance $Z$ is well known to be circular arc on a complex plane which consists of equivalent series resistance $R_s$ (real part) and equivalent series reactance $X_s$ (imaginary part). The frequency locus is called Cole-Cole circular arc \([6]\) and is expressed by the following equation that is Cole-Cole circular arc’s law

$$Z = R_s - jX_s = Z_\infty + \frac{Z_0 - Z_\infty}{1 + (j f / f_m)^\beta}$$ \hspace{1cm} (1)

where $f$ is frequency, $Z_0$, $Z_\infty$ are both resistances based on ion conductivity. $Z_0 = \lim_{\omega \to 0} Z$, $Z_\infty = \lim_{\omega \to \infty} Z$. $f_m$ is frequency which gives maximum reactance of $X_s$. The central relaxation time $\tau_m$, which shows dielectric relaxation phenomena, equals $1/(2\pi f_m)$. $\beta$ represents degree of distribution of relaxation time. The extracellular fluid resistance $R_e$ and the intracellular fluid resistance $R_i$ are expressed by $R_e = Z_0$ and $R_i = Z_0 Z_\infty / (Z_0 - Z_\infty)$, respectively.

2.2. Measuring system and throwing method

The measuring system of frequency characteristics of bioelectrical impedance with high time resolution was used \([3, 4]\). The 10 frequency points were the following 4, 8, 10, 16, 32, 40, 64, 80, 100 times harmonics as fundamental wave \((0.9765625 \text{ kHz})\). The parameters of impedance were calculated by an optimized calculation method \((\text{KH method}) \,[7]\). In order to confirm relations between these impedance parameters and throwing motions, images of 125 fps of throwing motion were taken a high-speed camera \((\text{VFC–1000SC, FOR-A})\). Figure 1 shows locations of electrodes. The measured part of forearm were a part between potential electrodes\((P^+, P^-)\).

The forearm electrical impedances of three subjects, who were Sub. A, B and C, were measured during four types of throwing a baseball \((\text{Th1, Th2, Th3 and Th4})\). These four types of throwing were the following different motions after ball release: \(\bullet \) Th1 excessive pronation; \(\bullet \) Th2 hyperextension of elbow joint; \(\bullet \) Th3 excessive spination; and \(\bullet \) Th4 natural pronation as shown in Fig. 2. From Th1 to Th3 are easily-hurt motion and Th4 is normal motion.

![Figure 1. Locations of electrodes. Current electrode \((I^+)\), potential electrode \((P^+)\), potential electrode \((P^-)\) and current electrode \((I^-)\) are shown in order from the left.](image1)

(a) Th1: excessive pronation  \hspace{1cm} (b) Th2: hyperextension of elbow joint

(c) Th3: excessive spination \hspace{1cm} (d) Th4: natural pronation (normal)

![Figure 2. Four types of throwing a baseball. Each picture shows just after release a baseball.](image2)
Multiple discrimination analysis

The change ratio of impedance parameters, $\Delta R_e, \Delta R_i, \Delta Z_\infty, \Delta f_m, \Delta \beta$, were calculated [4]. In time-series parameters, we defined three time point as follows: • $t_1$ when wrist joint were fully dorsiflexed; • $t_2$ when elbow joint were fully extended and fingers were also flexed; and • $t_3$ when maximum motion of forearm after ball release. We also defined $T$ which is time difference from $t_1$ to $t_3$. The 11 parameters, — which consist of five parameters in $t_2$ ($\Delta R_e(t_2), \Delta R_i(t_2), \Delta Z_\infty(t_2), \Delta f_m(t_2), \Delta \beta(t_2)$), those in $t_3$ ($\Delta R_e(t_3), \Delta R_i(t_3), \Delta Z_\infty(t_3), \Delta f_m(t_3), \Delta \beta(t_3)$), and $T$ —, were analyzed for multiple discrimination. 10 throwings in each motion were used for calculation for discriminate coefficient, other 10 throwings in each motion were analyzed for discrimination.

3. Results and Discussions

Fig. 3 shows sample of change ratios of impedance parameters, time points and images of throwing motions. There were ball release between $t_1$ and $t_2$. There were two common points of each throwing as follows: • After $\Delta f_m$ became local maximum value around $t = 2.5$ s in Fig. 3, it became local minimum value; • After $\Delta f_m$ became local maximum value, $\Delta R_e, \Delta R_i$ and $\Delta Z_\infty$ became local maximum values. There were also different among each local maximum values of $R_e, R_i, Z_\infty$ after $\Delta f_m$ became local maximum values. The common points and difference points of throwing a baseball were common among each subject. Therefore a discrimination may be effective using time points $t_1$–$t_3$ defined as the mentioned above and change ratio of parameters in that time point.

Table 1 shows standardized discriminate coefficient and contribution ratio of each vector in Sub. A. The absolute values of $\Delta R_e, \Delta R_i$ and $\Delta Z_\infty$ were larger than the other parameters in every vector. These three parameters greatly contributed to discrimination of throwing a baseball. There were same tendency in the other subjects. The cumulative contribution ratio in 1st and 2nd vectors were 91.7% and quite high.
Table 1. Standardized discriminate coefficient and contribution ratio of each vector in Sub. A.

| Discriminant motion | 1st vec. | 2nd vec. | 3rd vec. |
|---------------------|---------|---------|---------|
| ΔRc(t2)             | -14.375| 4.573   | -5.963  |
| ΔRc(t3)             | -10.828| 4.413   | -4.814  |
| ΔZ∞(t2)             | 17.127 | -6.016  | 7.795   |
| Δβ(t2)              | -0.282 | -0.481  | -0.423  |
| ΔRc(t3)             | 7.447  | 0.363   | 10.356  |
| ΔRc(t3)             | 6.494  | -0.526  | 9.635   |
| ΔZ∞(t3)             | -8.668 | 0.606   | -15.047 |
| Δβ(t3)              | 1.003  | 1.144   | -1.960  |
| T                   | 0.106  | 0.800   | 0.335   |

| contribution ratio [%] | 66.3 | 25.4 | 8.3 |

Table 2. Result of discrimination analysis for 120 throwings in three subjects.

| Discriminant motion | Th1 | Th2 | Th3 | Th4 |
|---------------------|-----|-----|-----|-----|
| True motion         |     |     |     |     |
| Th1                 | 25  | 0   | 0   | 5   |
| Th2                 | 0   | 30  | 0   | 0   |
| Th3                 | 0   | 0   | 30  | 0   |
| Th4                 | 0   | 0   | 0   | 30  |
| total               | 25  | 30  | 30  | 35  |

Table 2 shows result of discrimination analysis for 120 throwings in three subjects. We confirmed that the temporal change ratios had individual characteristics and there were different temporal change ratios among throwing a baseball. The individual hitting ratios were 95.0% for Sub. A, 92.5% for Sub. B and 100% for Sub. C. Five Th1, –excessive pronation–, were mistaken for Th4, –natural pronation–. This was caused by the same movement (pronation) in Th1 and Th4.

4. Conclusion

In order to discriminate throwing a baseball, we measured impedance parameters using the measuring system of frequency characteristics of bioelectrical impedance with high time resolution during four types of throwing a baseball. We confirmed that the temporal change ratios had individual characteristics and there were different temporal change ratios among throwing a baseball. The hitting ratio of discrimination analysis for 120 throwings in three subjects were very high and 95.8%. We can expect to discriminate throwing a baseball using multiple discriminant analysis of impedance parameters despite needs of pre-measurement to calculate equations for discrimination.

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