RELATION BETWEEN BODY COMPOSITION AND PHYSICAL ATHLETIC PERFORMANCE OF LONG DISTANCE RELAY RUNNERS PRODUCED BY A FOUR WEEK WEIGHT LOSS PROGRAM

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Abstract

The purpose of this study was to examine the relation between body composition and athletic performance of long distance relay runners in a four week weight reduction program. Six male collegiate runners, aged 19.0 ± 0.9 years, participated in this study. Body water content and fat free mass (FFM) were measured by bioelectrical impedance spectroscopy.

The weight loss by 4.1% of the initial body weight consisted of decreases in FFM and fat mass (54% and 46% respectively). Percentage of body fat did not change significantly by the end of the fourth week. The total body water (TBW) loss comprised of intracellular water (ICW) and extracellular water (ECW) at the end of the fourth week, and TBW loss and FFM loss were nearly the same values. Isokinetic muscular strength of right thigh, maximal oxygen intake (VO2max) and total treadmill running time (maximal workout time) measured did not show any significant change. These results indicate (1) half of the weight loss consisted of decrease in FFM, (2) TBW loss was due to the reduction of ICW and ECW, (3) the content of FFM loss was considered to be body water, and (4) there was no impact on muscular strength of right thigh, VO2max or maximal workout time.


Introduction

Numerous physical and psychological studies have examined the relation between body weight reduction and athletic performance and health in weight category sports, including wrestling1−7, boxing4,8, weight lifting3,4,9−12 and martial arts such as karate13−15 and judo16−20. However, there has been little research of the effect of body weight reduction on athletic performance and health in non-weight category sports such as gymnastics9,21 and long distance relay running22. Participants in non-weight category sports reduce body weight to achieve a better performance. Body weight reduction seems to decrease knee and leg loading23,24, thereafter by improving both speed and endurance and decreasing the incidence of injury. In contrast, this may also cause dehydration, which will affect the intracellular water (ICW) and extracellular water (ECW) athletic performance and health. Therefore, to carry out body weight reduction safely and effectively even in non-weight category sports, it is necessary to monitor changes in body water and athletic performance.

Total body water (TBW) is about 60% of the human body weight, and about 40% of this consists of ICW and the remainder (about 20%) is ECW25. ECW consists of 15% intercellular water and 5% plasma26. ICW is where chemical reactions27 and energy production take place, and its change can

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affect metabolism in cells, and even endanger life\textsuperscript{28}. As the permissible level of fluctuation within which ICW can maintain its function is about 10%, ICW is generally believed not to change. Moreover, alterations in the volume of plasma heavily affect blood circulation and blood pressure, so this volume would not be subject to significant change. Therefore, the change in the volume of body water is presumed to be due to the change in the volume of intercellular water\textsuperscript{27}. Since ICW and ECW differ in the functions and volumes, changes in TBW through body weight reduction should be examined in terms of ICW and ECW respectively.

With regard to athletic performance, there have been studies\textsuperscript{2,3,12} that showed a decline of performance through body weight reduction, whereas some\textsuperscript{2,5,10,11,29} showed no changes of performance or better performance despite decrease of fat free mass (FFM). We hypothesized that in non-weight category sports athletic performance improves through body weight reduction of one month.

Accordingly, the present study examined the relation between body composition and physical working capacity of six long distance relay runners through a four week weight reduction program. Body composition were measured using bioelectrical impedance spectroscopy (BIS).

Materials and Methods

Subjects

Six male collegiate long distance relay runners, 19 \pm 0.9 years old, participated in this study. All were thoroughly apprised of the experimental goals and potential risks and gave their informed consent. The study protocol was approved by Nippon Sport Science University ethics committee. The physical characteristics of the subjects are shown in Table 1.

Experimental protocol

All measurements were taken during selected mornings and evenings in June. The experiment itself was performed during that month. All subjects were denied food and drink for eight hours prior to the measurements in the mornings and were denied alcohol consumption from the previous day. The subjects were directed, as far as possible, to maintain the consumption of their breakfast and dinner as arranged by a dietician at the dormitories, to be denied food and drink anything other than water between meals, and to achieve a body weight reduction of 5%. Nutrient intake was investigated three days a week during the program. Subjects were given a verbal explanation of how to properly record the food eaten. Diet records were analyzed with the "Health-Make" software application. The main method of body weight reduction was dieting according to nutrient intake (Table 2) and living activity sheets of the subjects.

The height, weight, ICW and ECW of the entire body and FFM of all subjects were taken prior to the program and at the end of the second and fourth weeks. Hematocrit (Hct), plasma osmotic pressure

| Table 1. Changes in physical characteristics and body composition of the subjects during body weight reduction. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | 1 Pre           | 2 Second week   | 3 Fourth week   | Main effect     | Multiple comparison |
| Age (years)     | 19.0 ± 0.9      | 16.9 ± 3.9      | 16.7 ± 3.9      | ns              | \textgreater 2, 3, 4 |
| Height (cm)     | 169.0 ± 4.1     | 169.0 ± 3.9     | 168.7 ± 3.9     | \textgreater 3, 4 | \textgreater 3, 4 |
| Weight (kg)     | 58.5 ± 3.8      | 57.8 ± 3.7      | 56.1 ± 3.7      | \textgreater 3, 4 | \textgreater 3, 4 |
| FFM (kg)        | 47.8 ± 3.2      | 47.6 ± 3.2      | 46.5 ± 2.9      | *               | \textgreater 2, 3 |
| FM (kg)         | 10.7 ± 1.7      | 10.2 ± 2.3      | 9.6 ± 2.6       | *               | \textgreater 2, 3 |
| %Fat (%)        | 18.2 ± 2.5      | 17.5 ± 3.6      | 17.7 ± 3.1      | ns              | \textgreater 3, 4 |
| ECW (L)         | 22.2 ± 1.5      | 21.8 ± 1.4      | 21.3 ± 1.1      | *               | \textgreater 3, 4 |
| ECW (L)         | 15.3 ± 1.2      | 15.5 ± 1.2      | 15.0 ± 1.1      | *               | \textgreater 3, 4 |
| TBW (L)         | 37.5 ± 2.5      | 37.3 ± 2.4      | 36.2 ± 2.0      | \textgreater 3, 4 | \textgreater 3, 4 |

Values are means±SD; n=6.\textgreater:* : p<0.05; ** : p<0.01; *** : p<0.001; ns : no significance; Pre : before the weight reduction program; Second week : at the end of the second week of the program; Fourth week : at the end of the fourth week of the program; FFM: fat free mass; FM: fat mass; %Fat : percentage of body fat; ICW: intracellular water; ECW: extracellular water, TBW : total body water.
Table 2. Changes in nutrient intakes during body weight reduction.

<table>
<thead>
<tr>
<th></th>
<th>Pre</th>
<th>First week</th>
<th>Second week</th>
<th>Third week</th>
<th>Fourth week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>2096.5 ± 138.1</td>
<td>2051.0 ± 234.4</td>
<td>2130.0 ± 414.9</td>
<td>1855.3 ± 644.3</td>
<td>1265.6 ± 477.7</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>81.6 ± 20.1</td>
<td>60.2 ± 7.9</td>
<td>76.3 ± 17.3</td>
<td>75.9 ± 33.6</td>
<td>40.3 ± 18.1</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>66.6 ± 17.2</td>
<td>65.7 ± 10.5</td>
<td>73.9 ± 38.2</td>
<td>51.4 ± 22.1</td>
<td>38.8 ± 21.8</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>279.9 ± 53.3</td>
<td>289.1 ± 68.1</td>
<td>273.1 ± 45.6</td>
<td>258.9 ± 90.2</td>
<td>182.5 ± 54.5</td>
</tr>
</tbody>
</table>

Values are mean ± SD; n=4. *: p<0.05; ns: no significance. The number of the subjects who submitted all the nutrient intake sheets of the days before the program and on the first, second, third and fourth weeks totaled four. Pre: a day before the weight reduction program; First week: a day in the first week of the program; Second week: a day in the second week of the program; Third week: a day in the third week; Fourth week: a day in the fourth week of the program.

and various blood biochemical variables were also measured prior to the program and at the end of the second and fourth weeks. Maximal oxygen intake (VO₂max) and the total treadmill running time (maximal workout time) were also determined. The isometric and isokinetic muscular strength of knee extension and flexion movements were measured over 5 hours after VO₂max measurements were finished.

Height and Weight

The height and weight of all subjects were determined within 0.1 cm and 0.1 kg by a Tanita TBF-202MJ body fat analyzer.

ICW, ECW and FFM

ICW and ECW of the entire body and FFM were measured after acquiring subjects' height and weight data using a 4000C Bio-Impedance Spectrum Analyzer (Xitron Technologies, San Diego, CA, USA) operating at 200 µA. These measurements were taken according to the operating manual of the 4000C Bio-Impedance Spectrum Analyzer[30]. Three values were taken and their mean calculated.

Measurements were taken of the ICW and ECW of the entire body with electrodes (BIS-4000: width 1.9 cm, length 7.7 cm) placed on the wrist and ankle of the subjects. Two voltage-detector electrodes were situated midway on the line connecting the centers of prominent ends of the radius and ulna of the right wrist, and midway on the line connecting the centers of the medial and lateral malleoli of the right ankle. Two current-injection electrodes were placed both on the right hand and foot on the dorsal surfaces proximal to the metacarpal-phalanageal and metatarsal-phalanageal joints, respectively. All electrode positions were cleaned with alcohol and rubbed with BIS gel prior to electrode attachment. All electrodes used were specific to BIS methods. The 4000C analyzer was self-calibrated before each measurement was taken. All subjects wore fresh t-shirts and shorts during the measurements and rested in a supine position on a wooden table with their arms comfortably abducted from the body at an angle of 15 degrees and their legs slightly separated. They lay down for about 15 minutes during the application of the electrodes prior to the measurements.

Resistance and reactance were measured at 50 varying frequencies within the 5 kHz–1 MHz range (Extra and intracellular water: 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20, 23, 31, 35, 39, 43, 50, 54, 60, 67, 67, 75, 83, 93, 100, 115, 128, 143, 159, 177, 200, 220, 245, 273, 304, 339, 378, 421, 469, 500, 582, 649, 723, 806, 898, and 1000 kHz. Extracellular water: 5, 6, 7, 8, 10, 12, 14, 16, 20, 25, 31, 35, 43, 50, 67, 83, 100, 128, 159, 200 kHz). The A and Z for each frequency were computed by the instrument. The Z and θ spectra data are fitted to the Cole–Cole model, equation (1), using iterative non-linear curve fitting software. The Cole model is extended to allow for the frequency invariant time delay (T_D), caused by the speed at which electrical information is transferred through a conductor. The error introduced by
this fixed time delay is modeled as a phase error
that increases linearly with frequency. This linear
phase error is mathematically modeled by multipli-
ying equation (1) by the factor \( e^{j\omega T_d} \). Thus, the
overall modeled equation is:

\[
Z_{obs} = \left( \frac{R_F}{(R_F + R_l)} \right) \left( R_l + \frac{R_F}{1 + j\omega C_M(R_F + R_l)} \right)^{j\omega T_d} \tag{1}
\]

where

\( Z_{obs} \) is the observed complex impedance
\( R_F, R_l \) and \( C_M \) are the component values of this
circuit
\( \omega \) is frequency in radians/sec (= \( 2 \pi \times \) frequency)
\( j = \sqrt{-1} \)
\( F_C \) is computed after the model components \( R_F, R_l, C_M, T_D \) and \( a \) has been determined by solving the equation:

\[
\partial X(F_C) \quad \frac{\partial}{\partial \omega} = 0 \tag{2}
\]

where

\( X(F_C) \) is the imaginary part of equation (1) at fre-
cquency \( F_C \).

ECW and ICW are predicted from the modeled \( R_F \) and \( R_l \), using equations formulated from Hanai mix-
ture theory\(^{31}\). The Hanai equation describes the
effect which a concentration of non-conductive mate-
rial has on the apparent resistivity of the surround-
ing conductive fluid, and is:

\[
\rho = \frac{\rho_0}{(1 - C)^{5/2}} \tag{3}
\]

where

\( \rho \) is the apparent resistivity of a conductive mate-
rial.
\( \rho_0 \) is the actual resistivity of a conductive mate-
rial.
\( C \) is volumetric concentration of the non-conductive
material contained in the mixture.

From equation (3), with the following assumptions,
we derived a set of equations as follows:

\[
V_{ECW} = k_{ECW} \left( \frac{L^2}{R_E} \right)^{2/3} \tag{4}
\]

where

\( V_{ECW} \) is the predicted total extracellular fluid
volume (Liters)

\[
k_{ECW} = \frac{1}{1000} \left( \frac{K_B^2 \rho_{ECW}^2}{D_B} \right)^{1/3} \tag{5}
\]

\( W \) is body weight (kg)
\( L \) is height (cm)
\( R_E \) is the value from the model fitting (Ω)
\( K_B \) is a factor, correcting for a whole body
measurement between wrist and ankle, relating the
relative proportions of the leg, arm, trunk and
height.

\( \rho_{ECW} \) is the resistivity of extracellular fluid
(Ω·cm)

\[
D_B = \text{body density (kg/L)}
\]

\[
\left( 1 + \frac{V_{ECW}}{V_{ECW}} \right)^{5/2} = \left( \frac{R_F + R_l}{R_l} \right) \left( 1 + k \rho V_{ECW} \right) \tag{6}
\]

where

\[
k = \rho_{ECW} \tag{7}
\]

\( R_l \) is the value from the model fitting (Ω)

The following assumptions are made:
1. The volumetric concentration of non-conductive
   elements in the body at low frequencies is given
   by
\[
\left( 1 - \frac{V_{ECW}}{V_{TOT}} \right) \text{where } V_{TOT} \text{ is the total body volume}
\]
2. The volumetric concentration of non-conductive
   elements in the body at high frequencies is given by
\[
\left( 1 - \frac{V_{ECW} + V_{ICW}}{V_{TOT}} \right)
\]
3. Total body volume is Body Weight (W)·Body
   Density (D_B)
4. The total volume of a body fluid can be de-
   scribed by
\[
V_F = K_B \rho_F \frac{L^2}{R} \tag{8}
\]

where

\( V_F \) is the total volume of the fluid in the body.
\( K_B \) is a factor relating the relative proportions of
the leg, arm, torso and height.
\( \rho_F \) is the resistivity of the fluid.
\( L \) is body height.
\( R \) is the measured resistance between wrist and
ankle.
The factors \( D_B, K_B \) and \( \rho_F \) can be considered
largely constant.

The Hanai equation is applicable at high and low frequencies to mixtures found in the human body. Using equations 4 and 6, predicted $V_{\text{ECW}}$ and $V_{\text{ICW}}$ were computed, from which predicted TBW is computed using the following equations:

$$\text{TBW} = V_{\text{ECW}} + V_{\text{ICW}} \quad (9)$$

$$\text{FFM} = (d_{\text{ECW}} V_{\text{ECW}}) + (d_{\text{ICW}} V_{\text{ICW}}) \quad (10)$$

$d_{\text{ECW}}$ is the mean apparent density of ECW and associated materials.

$d_{\text{ICW}}$ is the mean apparent density of ICW and associated materials.

The fat mass ($\text{FM}$) of the subjects was obtained by subtracting FFM from the body weight. Percentage of body fat ($\%\text{Fat}$) was obtained by dividing the FM by the body weight and multiplying by 100. Reliability of this method, expressed as the coefficient of variation in repeated measures, has been reported to be 1–1.5%.

**Isokinetic and isometric muscular strength**

All subjects performed isokinetic and isometric knee extension and flexion tests. These tests were performed with a Biodex isokinetic dynamometer with system 3 over five hours after $\text{VO}_{2\text{max}}$ measurements. The subjects rested between $\text{VO}_{2\text{max}}$ and muscular strength tests. The strength tests consisted of right knee extension and flexion exercises. During the tests, the right thigh, waist and thorax were restrained with straps, while the arms rested on the chests. The range of motion during the extension–flexion tests was $0 \sim 90$ degrees, with 0 degree denoting full leg extension. All subjects completed exercises with maximal–intensity repetitions at 0, 60, 180 and 300 degrees/sec. Between each exercise test, they recovered fully from fatigue. Tests of right knee extension and flexion at 0 deg/sec, that is, isometric of knee extension and flexion were one maximal–intensity trial lasting 5 seconds.

**Blood samples**

All subjects urinated to completely empty their bladders prior to exercise. Blood was collected before the maximal workout test in the morning after eight hours overnight without food and drink. Blood samples were drawn from the antecubital vein while subjects were resting in a seated position.

Hct was measured by the micro-hematocrit method and hemoglobin concentration was determined by the cyanmethemoglobin method. Plasma osmotic pressure was determined through the freezing point depression method with 3D3 Advance. Blood concentrations of solutes such as blood urea nitrogen (BUN), albumin (ALB), total protein (TP), triglyceride (TG) and glucose (GLU) were determined through the dry-chemistry method using Fuji Dri-Chem 3500 (Fuji Film).

**Measurement of $\text{VO}_{2\text{max}}$**

All subjects took an incremental maximal treadmill-based workout test to determine their $\text{VO}_{2\text{max}}$ and maximal workout time. The initial treadmill speed was 222 m/min for 2 minutes and subsequently increased to 245 m/min, 267 m/min, 293 m/min, 316 m/min and 333 m/min for 3 minute increments. During all incremental tests the treadmill was set at a 3% incline and the maximal workout time was recorded. $\text{VO}_{2\text{max}}$ was taken when three of these four criteria were achieved: 1) leveling-off of the increase in $\text{VO}_{2}$, 2) respiratory exchange ratio exceeding 1.0, 3) rating of perceived exertion over 19 and 4) a maximum heart rate (HR) over 190 bpm. During the tests expelled gases were continuously collected and their values calculated (Sensor Medics 2900, Sensor Medics Corp., Yorba Linda CA) every 20 seconds by the mixing chamber method. Prior to each test the gas analyzer was calibrated with standard gas mixtures. Heart rates were monitored throughout the tests with an ECG.

**Seasonal training program**

All subjects followed their usual training program except for during the test days throughout the weight reduction program. During their seasonal training program they practiced for 90 minutes in the morning and in the evening practiced about 2
Table 3. Changes in blood properties during body weight reduction.

<table>
<thead>
<tr>
<th></th>
<th>① Pre</th>
<th>② Second week</th>
<th>③ Fourth week</th>
<th>Main effect</th>
<th>Multiple comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hct (%)</td>
<td>43.8 ± 2.2</td>
<td>42.9 ± 1.9</td>
<td>43.8 ± 3.1</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Plasma osmotic pressure (osmol/L)</td>
<td>287.5 ± 4.5</td>
<td>290.1 ± 3.0</td>
<td>294.9 ± 4.5</td>
<td>*</td>
<td>①&lt;③</td>
</tr>
<tr>
<td>Hb (g/dl)</td>
<td>14.9 ± 0.4</td>
<td>13.8 ± 0.7</td>
<td>14.4 ± 0.9</td>
<td>*</td>
<td>①&gt;②</td>
</tr>
<tr>
<td>ALB (g/dl)</td>
<td>4.4 ± 0.1</td>
<td>4.4 ± 0.2</td>
<td>4.8 ± 0.3</td>
<td>*</td>
<td>②&lt;③</td>
</tr>
<tr>
<td>BUN (mg/dl)</td>
<td>18.9 ± 4.4</td>
<td>20.7 ± 3.4</td>
<td>22.9 ± 3.6</td>
<td>*</td>
<td>①&lt;③</td>
</tr>
<tr>
<td>TP (g/dl)</td>
<td>7.3 ± 0.3</td>
<td>7.4 ± 0.5</td>
<td>7.6 ± 0.6</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>TG (mg/dl)</td>
<td>51.5 ± 15.9</td>
<td>41.7 ± 15.0</td>
<td>35.5 ± 11.6</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>GLU (mg/dl)</td>
<td>97.4 ± 13.0</td>
<td>89.25 ± 7.5</td>
<td>87.375 ± 6.6</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD; n=6. *: p<0.05; ns: no significance; Pre: before the weight reduction program; Second week: at the end of the second week of the program; Fourth week: at the end of the fourth week of the program.

and a half hours. The morning practices included warming up and long distance running and the afternoon ones were mainly warming up and interval training (400 m x 10) or 12,000 m running.

Nutrient intake

The number of the subjects who submitted nutrient intake sheets for the days preceding the program and for the first, second, third and fourth weeks totaled four. The nutrient intake on one sample day during the fourth week decreased significantly (p<0.05) compared to the nutrient intake of the sample days prior to the program and during the previous three weeks of the program, as shown in Table 2.

Statistics

All values were expressed as mean and standard deviations (±SD). A repeated-measures analysis of variance and Tukey tests were used for the data analysis. Values less than p<0.05 were considered significant.

Results

All subjects showed a significant decrease in body weight at the end of the second and fourth week (p <0.05, p <0.001) of the program (Table 1). The subjects lost 1.3 kg of FFM by the end of fourth week, which was 54% of the total body weight loss. They lost 1.1 kg of FM, which was 46% of the total

Fig. 1. Changes in isometric and isokinetic muscular strength of the knee extension and flexion before and after body weight reduction. Pre: before the weight reduction program; 4 W: at the end of the fourth week of the program.
Table 4. Changes in maximal oxygen uptake, maximum heart rate and maximal workout time during body weight reduction.

<table>
<thead>
<tr>
<th></th>
<th>① Pre</th>
<th>② Second week</th>
<th>③ Fourth week</th>
<th>Main effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{V}O_2 \text{max} \text{ (ml/min)} )</td>
<td>3891.7 ± 330.6</td>
<td>3535.8 ± 274.0</td>
<td>3695.9 ± 431.9</td>
<td>ns</td>
</tr>
<tr>
<td>( \dot{V}O_2 \text{max} / \text{BW} \text{ (ml/kg/min)} )</td>
<td>66.9 ± 8.1</td>
<td>61.2 ± 2.4</td>
<td>65.8 ± 4.1</td>
<td>ns</td>
</tr>
<tr>
<td>HRmax (beats/min)</td>
<td>193.7 ± 10.3</td>
<td>191.0 ± 10.7</td>
<td>189.3 ± 11.3</td>
<td>ns</td>
</tr>
<tr>
<td>Maximal workout time (min)</td>
<td>12.0 ± 2.5</td>
<td>12.3 ± 1.6</td>
<td>12.2 ± 2.5</td>
<td>ns</td>
</tr>
</tbody>
</table>

Values are means ± SD; n=6. ns: no significance; Pre: before the weight reduction program; Second week: at the end of the second week of the program; Fourth week: at the the end of the fourth week of the program; \( \dot{V}O_2 \text{max} \): maximal oxygen uptake; BW: body weight; HRmax: maximum heart rate.

Body weight loss through a four week weight reduction program. The reduction in %Fat produced by the program was shown to be insignificant.

In marked contrast, the average whole body ICW decreased significantly (p<0.01) at the end of the fourth week compared to that prior to the program (Table 1). The ECW also decreased at the end of fourth week (p<0.01) compared to that at the end of the second week.

The Hb decreased significantly (p<0.05) at the end of the second week compared with its pre-regimen value (Table 3). The plasma osmotic pressure (p<0.05) and BUN (p<0.05) both increased significantly at the end of the fourth week relative to their pre-program values. The ALB measured at the end of the fourth week also increased significantly (p<0.05) compared with its second week value. TP and other blood indicators showed no significant changes.

The sole significant change in physical working capacity was indicated by a significant decrease (p<0.05) in knee flexion movement at 0 degree/sec, meaning the isometric knee flexion movement tests (Fig. 1). No significant changes in \( \dot{V}O_2 \text{max} \), \( \dot{V}O_2 \text{max}/\text{BW} \) or maximal workout time were observed at any point prior to or during the program (Table 4).

Discussion

By means of the bioelectrical impedance (BI) method at a single frequency, TBW and FFM can be estimated without much difficulty. However there is a strong possibility that the current at a single frequency of 50 kHz can not penetrate all cell membranes. When this occurs, only the impedance of ECW and a portion of ICW are measured. In comparison, BIS enables the measurement of impedance at numerous frequencies. Low frequency currents are conducted through the ECW, whereas at high frequencies the current is able to penetrate the cell membranes and is conducted throughout the ECW and ICW. When using the BIS, the impedance of ECW can be measured at low-frequency and the impedance of TBW (ICW + ECW) can be measured at high-frequency94. Then ECW and TBW can be calculated. The ICW can be obtained by subtracting ECW from TBW.

The BIS method itself has been validated through the comparison of relationships between BIS values and fluid volumes determined by standard tracer dilution methods92,33,35 and studies using BIS have been reported96,34,36–39.

The present study using BIS revealed a significant decrease in TBW and ICW measured at the end of the fourth week relative to that observed at the start of the program. Also, the fourth week ECW showed a significant decrease from that observed at the end of the second week. The TBW loss was thus inferred to result from the loss of both ICW and ECW. Toyoshima et al.15 examined changes in TBW, ICW and ECW in male karate athletes through a 7 day weight reduction program by BIS. They observed TBW and ECW decrease and indicated ECW decrease through acute weight reduction program.
Tsutsumi et al.\textsuperscript{30} also used BIS to determine ICW and ECW changes in male judo athletes during a 24 day weight reduction program. In that study a continuous decrease in ECW was observed, and the body weight loss of the male judo athletes started around the 15\textsuperscript{th} day of the 24 day weight reduction program and the day when their body weight showed a marked decrease was on the 18\textsuperscript{th} day. Therefore that body weight reduction could certainly be considered an acute weight reduction for one week. In acute body weight reduction, athletes reduce their body weight for 2 to 10 days before tournaments by dieting, fasting, increasing training time, reducing water intake and stimulating perspiration by running in warm clothes, having saunas or bathing\textsuperscript{3,11,15,17\textendash}19,20). In the present study the ratio of body weight loss at the end of the second week of the program to the total body weight loss at the fourth week was 30\%. According to the nutrient intake and living activity sheets of the subjects, the subjects reduced their body weight mainly by dieting and denying themselves anything to drink other than water and avoided stimulating perspiration by running in warm clothes, having saunas or bathing. Thus, the differences of the terms and methods in the body weight reductions could be considered the cause of the different results in ICW and ECW loss.

The present study examined the influence of changes in ICW and ECW on physical working capacity. ICW is where chemical reactions and energy production take place\textsuperscript{25}) and its change can affect athletic performance. The reduction in plasma or blood volumes causes the reduction of the stroke volume\textsuperscript{20}) that can affect athletic performance. Although in the current study ICW and ECW decreased significantly, there were no significant changes in muscular strength, \(\text{VO}_{2}\text{max}\), and maximal workout time. In this study TBW loss and FFM loss were nearly the same values. As a result the content of FFM loss was considered to be TBW loss. According to the above study by Toyoshima et al.\textsuperscript{15)}, ECW decreased significantly and muscular strength and \(\text{VO}_{2}\text{max}\) showed no changes and maximal work-

out time was significantly shortened. In that study\textsuperscript{15)} 1.5 liters of TBW loss and 2.1 kgs of FFM loss were observed. The content of FFM loss comprised 1.5 liters of TBW and the remainder, which could be body protein and other substances. The different contents of FFM loss in the two studies might generate different results of maximal workout time. In this respect further experiments are required.

From the change of blood properties in the current study, it is suggested that there was no dehydration and nutrient depletion throughout the program.

Many earlier studies\textsuperscript{6,7,10,11,15,20) have assessed FFM and FM during weight reduction programs. These studies have revealed the pivotal importance of simultaneously maintaining FFM and losing FM in improving physical working capacity. However, it has also been reported\textsuperscript{6,7,10,11,20) that FFM is lost during body weight reduction. It has also been reported\textsuperscript{10\textendash}44) that athletes with lower \%Fat show better performance. Therefore, regarding changes in performance through body weight reduction, the effect of changes in FFM and \%Fat through body weight reduction on athletic performance should be examined.

Matsuoka et al.\textsuperscript{10,11)} reported that in two 20 day weight reduction programs of 3.1\% and 6.1\% in the body weights of weight lifters using a high protein diet, FFM could not be maintained. The ratios of FFM loss to the total body weight loss in the two programs were 60\% and 50\% respectively, and the \%Fat decreased. Despite the fact that the ratio of FFM loss to the total body weight loss is generally more than 50\%, \%Fat is usually maintained or decreased, because the ratio of FFM to total body weight is larger than the ratio of FM to the total body weight. In contrast, according to Kitagawa et al.\textsuperscript{21)}, in a 33 day weight reduction study of female gymnasts, using a diet prepared by a dietitian, FFM showed no significant change and FM showed a significant decrease. In the present study, the ratios of FFM loss and FM loss to the total body weight loss at the end of the fourth week, with 4.1\% weight re-
duction, was 54 : 46. Therefore, these results indicate that it is difficult to maintain FFM while reducing FM through a body weight reduction program.

This study examined the influence of FFM on muscular strength, \( \dot{V}O_2 \text{max} \), and maximal workout time. \( \dot{V}O_2 \text{max} \) in particular is a good performance indicator for long distance runners\(^3\). FFM is correlated with muscular strength and \( \dot{V}O_2 \text{max} \)\(^{10,11,42,43}\). It showed no significant changes in isokinetic knee extension or flexion muscular strength at the selected angular speeds. The only significant change in knee performance shown was knee flexion movement at 0 degree/sec, as shown in Fig. 1. Kataoka et al.\(^3\) found a significant decrease of muscular strength in knee extension, but no significant change in elbow flexion, during a rapid weight reduction program. Matsuoka et al.\(^{10}\) found no change in maximal isometric strength in their study, despite an FFM loss of 55.1% relative to the total body weight loss. Kataoka et al.\(^3\) suggested that psychological factors significantly influence the exertion of muscular strength since the rate of body weight reduction is not proportional to that of decreasing muscular strength. Ono et al.\(^5\) indicated autonomic nerve activity produced sympathetic nerve strain through body weight reduction based upon the indication of an increase in muscular strength after body weight reduction in many studies. This present study assumes, despite decreasing FFM, that muscular strength is unaffected by sympathetic nerve strain or psychological factors. This study also showed no significant changes in either \( \dot{V}O_2 \text{max} \), \( \dot{V}O_2 \text{max}/BW \) or maximal workout time during the program. As regards to rapid weight reduction for athletes in weight category sports, Kataoka et al.\(^{12}\) examined changes in \( \dot{V}O_2 \text{max} \), \( \dot{V}O_2 \text{max}/BW \) and maximal workout time after 6 to 7 day weight reductions of 5.8% and 7.85% for male wrestlers and weight lifters respectively. That study revealed a significant decrease in \( \dot{V}O_2 \text{max} \), \( \dot{V}O_2 \text{max}/BW \) and a significantly shortened maximal workout time. By contrast, Matsuoka et al.\(^{11}\) observed no change in \( \dot{V}O_2 \text{max} \) and a pronounced increase in \( \dot{V}O_2 \text{max}/BW \), although FFM loss was equivalent to 61% of the total body weight lost. Haga et al.\(^{39}\) observed no changes in either \( \dot{V}O_2 \text{max} \) or \( \dot{V}O_2 \text{max}/BW \), although FFM was reduced through their rapid weight reduction program. They suggested that \( \dot{V}O_2 \text{max} \) is maintained by the extension of an arteriovenous oxygen difference. Ono et al.\(^{53}\) examined changes in blood circulation produced by rapid weight reduction in wrestlers. This indicates that sympathetic nerve stimulation increases heart rates and enhances overall heart contraction in compensation for a sizable decrease in stroke volume. In a longer weight reduction program, Matsuoka et al.\(^{11}\) measured the \( \dot{V}O_2 \text{max} \) of weight lifters after a 20 day weight reduction of 6.1% in combination with a high protein diet. They observed no change in \( \dot{V}O_2 \text{max} \) but a significant increase in \( \dot{V}O_2 \text{max}/BW \). These results indicated that despite decreasing FFM, \( \dot{V}O_2 \text{max} \) and \( \dot{V}O_2 \text{max}/BW \) are possibly retained due to the above mentioned alternate actions in body weight reduction of athletes.

Further research is required to measure physical working capacity after athletes get accustomed to their body weight upon completion of the weight reduction program.

In conclusion, (1) half of the weight loss was FFM, (2) the decrease in body water must be due to the reduction of ICW and ECW, (3) the content of FFM loss was considered to be body water, and (4) this program did not influence physical working capacity. Further research is also required to examine the effect of body weight reduction over a longer running time, on leg injuries, and to assess physical working capacity after athletes get accustomed to their body weight upon completion of the weight reduction program.

**Acknowledgements**

This work was supported partly by the Hiroiike academic research promotion foundation.

The authors would like to thank Prof. Scott T. Davis, International School of Economics and Business Administration, Reitaku University and Robert Wilson, a lecturer at Tokai University for their critical reading of this
manuscript and for their great help.

(Accepted Oct. 7, 2004)

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