Body Composition and Power Changes in Elite Judo Athletes

Authors A. M. Silva[1], D. A. Fields[2], S. B. Heymsfield[3], L. B. Sardinha[1]

Affiliations Affiliation addresses are listed at the end of the article

Key words
- intracellular water
- total-body water
- upper-body power
- dilution methods

Abstract

The purpose of this study was to analyse the association between body composition changes, from a weight stable period to prior competition, on upper-body power in judo athletes. 27 top-level male athletes were evaluated at baseline (weight stable period) and 1–3 days before competition, with a time difference of approximately 1 month. Total body and extracellular water were estimated by dilution techniques (deuterium and bromide, respectively) and intracellular water was calculated as the difference. Body composition was assessed by DXA. A power-load spectrum was used to assess upper-body power output in a bench-press position. Comparison of means, bivariate, and partial correlations were used. Results indicate that though no significant mean changes were found in body composition and upper-body power, individual variability was large. Among all body composition changes, only total-body water ($r = 0.672$; $p < 0.001$) and intracellular water ($r = 0.596$; $p = 0.001$) were related to upper-body power variation. These associations remained significant after controlling for weight and arm lean-soft tissue changes ($r = 0.594$, $p = 0.002$ for total-body water; $r = 0.524$, $p = 0.007$ for intracellular water). These findings highlight the need for tracking total-body water, specifically the intracellular compartment in elite judo athletes in order to avoid reductions in upper-body power when a target body weight is desired prior to competition.

accepted after revision
May 15, 2010

Bibliography
DOI http://dx.doi.org/10.1055/s-0030-1255115
Published online:
July 19, 2010
Int J Sports Med 2010; 31: 737–741 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

Correspondence
Analiza Mónica Silva
Faculty of Human Kinetics
Technical University of Lisbon
Exercise and Health Laboratory
Estrada da Costa
1495-688 Cruz-Quebrada
Portugal
Tel.: +35/121/414 9160
Fax: +35/121/414 9193
analiza@fmh.utl.pt

Introduction

Water consumption, hydration status, and the effects of dehydration on exercise and work performance, health, and well-being have been the topic of much public and scientific debate in recent years [6]. The effect of body water balance on aspects of exercise performance has been extensively researched and, in recent years, reviewed comprehensively [14,20]. Judelson and colleagues [14] indicated dehydration limits strength, power, high intensity endurance and, therefore, is an important factor to consider when attempting to maximize muscular performance in athletes.

Water is the most abundant component of body mass at the molecular level in healthy adults [24]. Water is distributed into 2 main compartments: intracellular (ICW) and extracellular (ECW). The reference methods for total body water (TBW) and ECW assessment are based on dilution techniques, such as deuterium and bromide, while ICW can be accurately assessed as the difference between TBW and ECW [21]. However, few studies have been conducted with athletes using these reference techniques [2,18,22]. Hence, the use of less valid techniques for assessing athletes has limited our understanding of the effects of hydration changes on performance [4,19].

Body water loss in humans results in fluid losses from both the intracellular and extracellular fluid compartments [7]. However, fluid losses from these 2 compartments can cause different effects on the remaining body water pools [13,17]. When body water loss has occurred, various effects on neuromuscular function and short-term power have been reported [14]. The published evidence suggests that there is a likelihood of a reduction in strength if dehydration is induced as a result of prolonged food and fluid restriction [3,14]. However, to our knowledge no literature has identified which of the main compartments of TBW (ECW and ICW) are decreased after fluid restriction and what are the respective consequences of these changes on physical performance, especially in power sports.

The purpose of the current study was to analyse the relationship between body composition changes and upper-body power output in male judo athletes.

Material and Methods

Subjects

27 male judo athletes were eligible to participate in the study. The inclusion criteria were: 1) age ≥18 years, 2) volitionally practiced rapid weight loss at least 3 times within the past year , 3) practiced judo for ≤5 years, 4) trains ≥15 h a week, 5) a level of > 1st degree black belt, 6) tested negative for performance enhancing drugs, and 7) not taking any medications or dietary supplements. Medical screening indicated no health limitation for study participation. All subjects were informed about the possible risks of the investigation before giving their written informed consent to participate. All procedures were approved by the Ethic Committee of the Faculty of Human Movement, Technical University of Lisbon. The present study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [10].

Experimental design

A sample of national top-level judo athletes, engaged in the sport for more than 7 years enrolled into the study. Data collection was performed between September (1 month after the beginning of the in-season) and December.
Body composition assessment was made during a period of weight stability and again 1–3 days prior to competition, with a time difference of approximately 1 month. The period of weight stability was considered the baseline phase with athletes performing their regular regimens of judo training which typically last ~2 h in the morning and ~2 h in the evening. 2 of the morning sessions were used for improving cardiorespiratory fitness and strength while the other sessions consisted of judo specific skills and drills and randori (fighting practice) with varying intensity above and below 90–95 % of VO_2max. Prior to competition some athletes lost body weight voluntarily restricting both fluid and food while others remained or increased their body weight.

Body composition measurements

Subjects came to the laboratory at baseline and prior to competition, after a 12-h fast, while refraining from exercise, alcohol, or stimulant beverages for at least 15 h. All measurements were carried out on the same morning.

Anthropometry

Subjects were weighed to the nearest 0.01 kg wearing a bathing suit without shoes on an electronic scale connected to the plethysmograph computer (BOD POD®. Life Measurement, Inc., Concord, CA, USA). Height was measured to the nearest 0.1 cm using a scale (Seca Hamburg, Germany) according to standardized procedures described elsewhere [16].

Fat mass (FM), Fat-free mass (FFM), Lean soft-tissue (LST), and Appendicular LST

Whole body composition using dual energy X-ray absorptiometry (QDR-4500, Hologic, Waltham, USA) was used to estimate FM, FFM, LST, and appendicular LST using 8.21 software. Scan positioning, acquisition, and analysis were standardized. Based on test-retest using 10 subjects, the coefficient of variation (CV) for FM and LST was 2.9 % and 1.7 %, respectively.

Total body water

TBW was assessed by deuterium dilution using a stable Hydra gas isotope ratio mass spectrometer (PDZ, Europa Scientific, UK). After a 12 h fast, an initial urine sample was collected followed by the administration of a deuterium oxide solution dose (^2H_2O) of 0.1 g/kg of body weight. After a 4 h equilibration period, a second urine sample was collected. TBW was estimated including a 4 % correction due to TBW exchanging with non-aqueous compartments [21]. Based on test-retest using 10 subjects, the CV was 0.4 %.

Extracellular water (ECW)

ECW was assessed by sodium bromide dilution. The subject was asked to drink 0.030 g/kg of body weight of NaBr. The NaBr concentration in plasma was measured by high-performance liquid chromatography (Dionex Corporation, Sunnyvale, CA) before and 3 h after tracer administration. The volume of ECW was calculated as: ECW(L) = [dose/{post-plasma bromide ($[Br]_{PLASMA}$) – pre($[Br]_{PLASMA}$)}] × 0.90 × 0.95 where 0.90 is a correction factor for intracellular bromide (Br^-), found mainly in red blood cells, and 0.95 is the Donnan equilibrium factor [21]. Based on test-retest using 7 subjects, the CV was 0.5 %.

Intracellular water (ICW)

ICW was also calculated as the difference between TBW and ECW using the dilution techniques mentioned above (deuterium and sodium bromide, respectively).

Hydration status

To assure all athletes were in a neutral hydration state at baseline (weight stability period) we used the combined information of athletes' post-voiding first-morning body weights in the 3 days prior to the first visit and the observation of urine colour, as proposed by Casa et al. [4]. If body weight changed by less than 1 % and pale yellow urine (the color of lemonade, 1–3 on the Urine Colour Chart) was observed, strong evidence existed that athletes were in a euhydrated condition [4].

Physical performance test – upper-body power output

After body composition was assessed a physical test representing strength capacities needed to powerfully push the opponent during successive short intensive bouts was performed. Therefore, upper-body power output (UBPO) was determined in a bench press machine interfaced to a computer for data analysis both at baseline and prior to the competition. During upper extremity test actions, bar displacement, average velocity (meters per second) and mean power (watts) were recorded by linking a rotary encoder to the end part of the bar. The rotary encoder recorded the position and direction of the bar. The rotary encoder recorded the position and direction of the bar within an accuracy of 0.0002 m. Customized software (JLML I+D, Madrid, Spain) was used to calculate the output of each repetition performed throughout the whole range of motion. Subjects performed the test lying in a supine position on at flat bench. Legs were positioned at the sides of the bench with feet flat on the floor. The bar was gripped with hands a shoulder width apart. The subjects started the test placing the bar close to the chest with forearms perpendicular to the floor in line with the shoulders. As fast as possible, the bar was pressed upwards extending the arms completely and immediately returning the bar back to the chest.

At baseline, a power-load spectrum (5 kg increment) was used to assess UBPO. Subjects performed 3 repetitions at each workload and the mean power output was recorded. A rest interval of 3 min was used between each workload. Before the competition, and after a standardized warm-up, only the individual load where the peak power output value was attained at baseline was used to assess power output changes. This option was made to avoid affecting the energy demands of the competition.

Table 1 Mean and standard deviation values for body composition, energy intake, and upper-body power output assessed at baseline, prior competition, and the respective changes.

	Baseline Mean ± SD	Prior Competition Mean ± SD	Changes* Mean ± SD
age (yrs)	23.2 ± 2.8		
stature (m)	1.76 ± 0.05		
weight (kg)	72.8 ± 7.1	72.0 ± 6.9	−1.1 ± 2.7#
BMI (kg/m^2)	23.6 ± 2.3	23.4 ± 2.2	−1.1 ± 2.7#
%FM	12.1 ± 3.1	11.7 ± 2.8	−2.7 ± 8.8
FM (kg)	8.8 ± 2.8	8.4 ± 2.5	−3.7 ± 10.7
FFM (kg)	63.4 ± 5.7	62.9 ± 5.8	−0.7 ± 2.4
LST (kg)	60.3 ± 5.4	59.9 ± 5.5	−0.7 ± 2.6
arms LST (kg)	7.4 ± 1.1	7.2 ± 1.0	−1.6 ± 4.4
legs LST (kg)	20.5 ± 1.8	20.3 ± 1.7	−0.6 ± 2.8
TBW (kg)	47.4 ± 4.8	47.1 ± 4.8	−0.6 ± 4.5
ECW (kg)	19.8 ± 2.2	19.6 ± 2.3	−0.9 ± 5.8
ICW (kg)	27.6 ± 3.2	27.5 ± 3.2	−0.4 ± 6.4
energy intake (kcal)	2486.3 ± 650.4	2340.0 ± 764.2	−3.2 ± 31.6
UBPO (watts)	467.0 ± 104.7	472.7 ± 83.6	2.9 ± 12.1

Abbreviations: BMI, body mass index; % FM, percent fat mass; FM, absolute fat mass; FFM, fat-free mass; LST, lean soft-tissue; TBW, total-body water; ICW, intracellular water; ECW, extracellular water; UBPO, upper-body power output.
* Changes are expressed as a percentage of the baseline value;
# significantly different from 0, $p < 0.05$

Energy intake

Energy intake was assessed during a period of 7 days using a 24-h diet record both at baseline and prior to competition. Subjects were instructed regarding portion sizes, supplements, food preparation, and others aspects pertaining to an accurate recording of their energy intake. Records were turned in and reviewed at the time of laboratory testing for macro and micro nutrient composition and total energy expenditure (kilocalories). Diet records were analysed using 2 software packages (Food Processor SQL and PIABAD).

Statistical Methods

Data was analysed with SPSS for Windows version 17.0 (SPSS Inc, Chicago). Descriptive statistics included means ± SD and were calculated for all outcome measurements.

Using 27 subjects, this study was 80 % powered to detect a correlation coefficient higher than 0.51 and as low as −0.51.

Comparison of mean changes was performed using paired samples T-Test while independent samples T-Tests were used for comparisons between groups. Changes were expressed as a percentage of the baseline value (variation). The relationship between body composition changes and physical performance was conducted by bivariate correlations. Partial correlations were used to adjust those relations for the changes in potential confounding variables.

For all tests, statistical significance was set at $p < 0.05$.

Results

Subject characteristics are presented in ▶ **Table 1**. A significant reduction ($p < 0.05$) of 1.1 kg in body weight was observed, ranging from −6.2 to 5.8 %, while no significant changes were found in FM, FFM, LST, arms and legs LST, TBW, ECW, ICW, energy

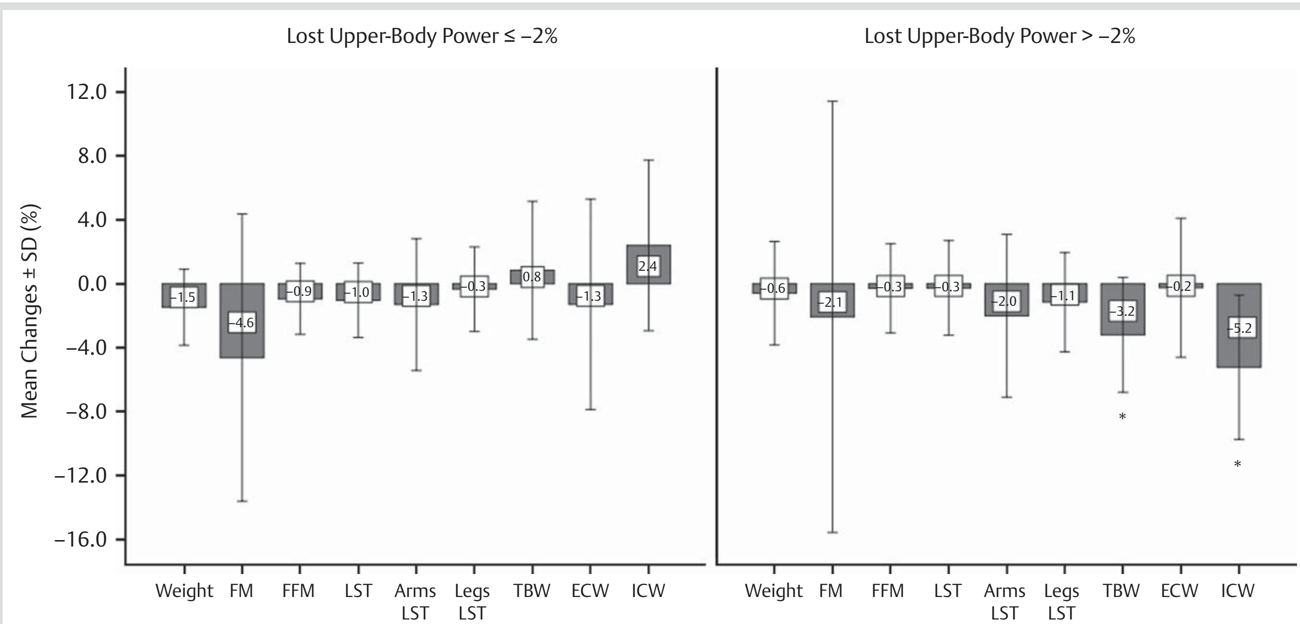

Fig. 1 Mean ± standard deviation (SD) for changes in body weight, fat mass (FM), fat-free mass (FFM), lean soft-tissue (LST), arms LST, legs LST, total-body water (TBW), extracellular water (ECW), and intracellular water (ICW) in athletes who lost upper-body power by less than −2 % (or gained) (N = 17) and those who lost more than −2 % (N = 10). Significant differences ($p < 0.05$) between groups are indicated by *.

intake and UBPO. Considering a cut-off point for UBPO of −2%, athletes were divided in 2 groups: those who lost more than −2% (10 athletes) and those who changed less (loss or gain) than −2% UBPO (17 athletes). ▸ **Fig. 1** indicates the mean changes in body weight, FM, FFM, LST, arms and legs LST, TBW, ECW, and ICW. Significant reductions were found in TBW and ICW ($p<0.05$) in those who lost upper-body power by more than −2% though no differences were found in the other body composition variables ($p<0.05$) when compared to those who lost upper-body power by less than -2% (or gained).

The association between alterations in UBPO and body composition is displayed in ▸ **Table 2**. Changes in UBPO were only related to changes in TBW and ICW. As observed in ▸ **Fig. 2**, those athletes who lost TBW and ICW were those that had a reduced UBPO. These associations remained after controlling for weight and arms LST changes ($r=0.594$, $p=0.002$ and $r=0.524$, $p=0.007$, respectively).

Discussion

The primary goal of this study was to examine the association between alterations in body composition and upper-body power, from a weight stability period to prior competition in elite judo athletes, with approximately 1 month apart between evaluations. Dilution techniques were uniquely used to assess TBW, ECW and ICW, thus offering more accurate estimates than provided by other commonly used methods to estimate body water and its compartments [9]. An important finding in our study was that those athletes with a more decreased upper-body power were those who had a greater reduction in TBW, even controlling for changes observed in body weight and arms lean soft-tissue. A recent review by Judelson et al. [14] indicated that decreases in TBW were related to decreases in muscular performance, specifically a 3–4% reduction in hydration results in a 2% reduction in muscular power [5,23]. However, these studies induced acute dehydration and hyperthermia which was not the case in our study, as subjects came to the laboratory approximately 1 month after the baseline evaluation, in a fasted state (12 h) with no exercise for at least 15 h. Additionally earlier studies did not use gold standard techniques to evaluate TBW nor did they assess the effect of ECW and ICW on muscular power.

The effect of changes in ECW and ICW on performance in athletes [8] is not reported in the literature. Our results indicated a clear relationship between changes in ICW and power output. A possible mechanism may be the cell swelling theory introduced by Haussinger in the 1990s [11,12,15]. This concept postulates that cellular volume is a key signal for the metabolic orientation of cell metabolism, namely cellular swelling leads to anabolism whereas cellular shrinkage promotes catabolism. The cell swelling theory is therefore very attractive as a possible mechanism for explaining why those athletes who increased the cellular water compartment increased muscular power, as cellular enlargement acts as an anabolic proliferative signal. Moreover, malnutrition induces extracellular expansion and intracellular water shrinkage [1]. In our findings, it is possible that a shift may have occurred between water compartments due to the fact that some of our athletes restricted their diet (energy intake changes ranged from −54% to 76%).

Unfortunately, in a clinical setting, the assessment of the intracellular space is largely ignored and no reference values are available to compare ICW measurements, specifically in athletes. Therefore, athletes do not know whether their ICW is in a healthy or unhealthy range and a medical practitioner cannot use an evidence-based target value for a rehydration strategy in a dehydrated person.

Table 2 Association between body composition variables and upper-body power output changes*.

Body Composition Variation	Upper-Body Power Output Changes (%)	
	Coefficient of correlation (r)	P-value
body weight changes (%)	0.255	0.200
FM changes (%)	0.232	0.244
FFM changes (%)	0.232	0.244
LST changes (%)	0.271	0.171
arms LST changes (%)	0.271	0.171
legs LST changes (%)	0.251	0.207
TBW changes (%)	0.672#	<0.001
ECW changes (%)	0.277	0.162
ICW changes (%)	0.596#	0.001

Abbreviations: FM, fat mass; FFM, fat-free mass; LST, lean soft-tissue; TBW, total-body water; ICW, intracellular water; ECW, extracellular water; UBPO.
* Changes are expressed as a percentage of the baseline value;
# Significant association ($p<0.01$)

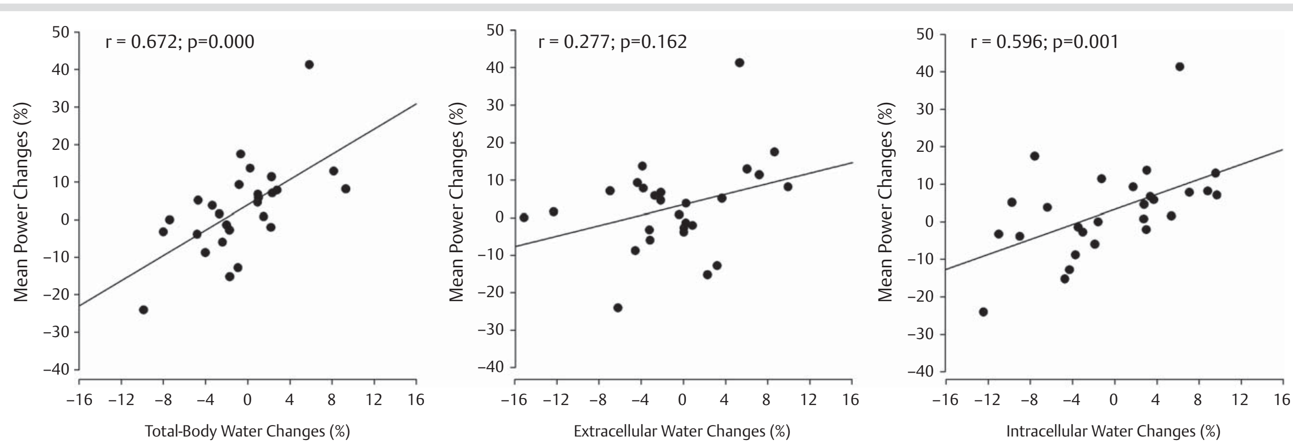

Fig. 2 Associations between changes in total-body water, extracellular water, and intracellular water with upper-body power output.

In conclusion, we observed that reductions in body water, particularly within the cells, are related with decreased upper-body power output in elite judo athletes. Moreover, measures of TBW and ICW should be performed in athletes that need to achieve a target body weight prior to competition and further studies should be employed to establish reference values for total and intracellular water in an athletic population.

Affiliations
[1] Faculty of Human Kinetics, Technical University of Lisbon, Exercise and Health Laboratory, Cruz-Quebrada, Portugal
[2] Children's Medical Research Institute's Diabetes and Metabolic Research Center, University of Oklahoma, Department of Pediatrics, Oklahoma City, United States
[3] Merck & Co., Scientific Affairs, Obesity, Rahway, United States

References

1 *Barac-Nieto M*, *Spurr GB*, *Lotero H*, *Maksud MG*. Body composition in chronic undernutrition. Am J Clin Nutr 1978; 31: 23–40
2 *Battistini N*, *Virgili F*, *Bedogni G*. Relative expansion of extracellular water in elite male athletes compared to recreational sportsmen. Ann Hum Biol 1994; 21: 609–612
3 *Bosco JS*, *Terjung RL*, *Greenleaf JE*. Effects of progressive hypohydration on maximal isometric muscular strength. J Sports Med Phys Fitness 1968; 8: 81–86
4 *Casa DJ*, *Clarkson PM*, *Roberts WO*. American College of Sports Medicine roundtable on hydration and physical activity: consensus statements. Curr Sports Med Rep 2005; 4: 115–127
5 *Cheuvront SN*, *Carter R* 3rd, *Haymes EM*, *Sawka MN*. No effect of moderate hypohydration or hyperthermia on anaerobic exercise performance. Med Sci Sports Exerc 2006; 38: 1093–1097
6 *Cheuvront SN*, *Carter R* 3rd, *Sawka MN*. Fluid balance and endurance exercise performance. Curr Sports Med Rep 2003; 2: 202–208
7 *Costill DL*, *Cote R*, *Fink W*. Muscle water and electrolytes following varied levels of dehydration in man. J Appl Physiol 1976; 40: 6–11
8 *Fellmann N*, *Ritz P*, *Ribeyre J*, *Beaufrere B*, *Delaitre M*, *Coudert J*. Intracellular hyperhydration induced by a 7-day endurance race. Eur J Appl Physiol 1999; 80: 353–359
9 *Gudivaka R*, *Schoeller DA*, *Kushner RF*, *Bolt MJ*. Single- and multifrequency models for bioelectrical impedance analysis of body water compartments. J Appl Physiol 1999; 87: 1087–1096
10 *Harriss DJ*, *Atkinson G*. International Journal of Sports Medicine – Ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2009; 30: 701–702
11 *Haussinger D*, *Lang F*, *Gerok W*. Regulation of cell function by the cellular hydration state. Am J Physiol 1994; 267: E343–E355
12 *Haussinger D*, *Roth E*, *Lang F*, *Gerok W*. Cellular hydration state: an important determinant of protein catabolism in health and disease. Lancet 1993; 341: 1330–1332
13 *Jennett S*. Sweating. In: Blakemore C, Jennett S (eds). The Oxford Companion to the Man. Oxford, UK. Oxford University Press; 2001; 667
14 *Judelson DA*, *Maresh CM*, *Anderson JM*, *Armstrong LE*, *Casa DJ*, *Kraemer WJ*, *Volek JS*. Hydration and muscular performance: does fluid balance affect strength, power and high-intensity endurance? Sports Med 2007; 37: 907–921
15 *Lang F*, *Busch GL*, *Ritter M*, *Volkl H*, *Waldegger S*, *Gulbins E*, *Haussinger D*. Functional significance of cell volume regulatory mechanisms. Physiol Rev 1998; 78: 247–306
16 *Lohman TG*, *Roche AF*, *Martorell R* (eds). Anthropometric Standardization Reference Manual. Champaign, IL, Human Kinetics Publishers; 1988
17 *Lote C*. Kidneys. In: Blakemore C, Jennett S (eds). The Oxford Companion to the Body. Oxford, UK, Oxford University Press; 2001; 416–418
18 *Quiterio AL*, *Silva AM*, *Minderico CS*, *Carnero EA*, *Fields DA*, *Sardinha LB*. Total body water measurements in adolescent athletes: a comparison of 6 field methods with deuterium dilution. J Streng Cond Res 2009; 23: 1225–1237
19 *Sawka MN*, *Burke LM*, *Eichner ER*, *Maughan RJ*, *Montain SJ*, *Stachenfeld NS*. American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 2007; 39: 377–390
20 *Sawka MN*, *Coyle EF*. Influence of body water and blood volume on thermoregulation and exercise performance in the heat. Exerc Sport Sci Rev 1999; 27: 167–218
21 *Schoeller DA*. Hydrometry. In: Heymsfield SB, Lohman TG, Wang Z, Going SB (eds) Human Body Composition. Champaign, IL, Human Kinetics; 2005; 35–49
22 *Silva AM*, *Minderico CS*, *Teixeira PJ*, *Pietrobelli A*, *Sardinha LB*. Body fat measurement in adolescent athletes: multicompartment molecular model comparison. Eur J Clin Nutr 2006; 60: 955–964
23 *Viitasalo JT*, *Kyrolainen H*, *Bosco C*, *Alen M*. Effects of rapid weight reduction on force production and vertical jumping height. Int J Sports Med 1987; 8: 281–285
24 *Wang Z*, *Deurenberg P*, *Wang W*, *Pietrobelli A*, *Baumgartner RN*, *Heymsfield SB*. Hydration of fat-free body mass: new physiological modeling approach. Am J Physiol 1999; 276: E995–E1003