Journal of Human Kinetics volume 21 2009, 65-74
Section II – Exercise Physiology & Nutrition **DOI 10.2478/v10078-09-0008-3**

The Recovery Phase Following a Triple Iron Triathlon

by
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The purpose of this case study was to investigate the recovery phase in a single athlete after a Triple Iron Triathlon involving 11.4 km swimming, 540 km cycling and 126.6 km running. Total body mass, body fat and skeletal muscle mass using the anthropometric method as well as total body water using bioelectrical impedance analysis were determined pre race, after the race and every 24 hours until complete recovery. Parameters of hydration status (urinary specific gravity, hematocrit and plasma sodium) and skeletal muscle damage (plasma urea) were measured at the same time. After finishing the race within 42 hours, total body mass was decreased and total body water was increased. Over the following 6 days, prior to returning to pre race values for plasma volume and total body water, body mass reached a peak value on day 3, plasma volume on day 2 and total body water on day 1. Clinically visible edemas of the feet persisted until day 4. Six days after the race, body mass was reduced by 2.1 kg, skeletal muscle mass by 0.6 kg and fat mass by 0.7 kg. An increase in both blood urea and urinary output post race between days 3 and 6 suggested an impairment of renal function immediately post race due to skeletal muscle damage and manifesting clinically observed edemas. For practical application, athletes, coaches and physicians should anticipate that performing such an ultra-endurance race can lead to considerable edemas of the lower limbs during the recovery phase.

Key words: total body water, fluids, edemas, body mass, ultra-endurance racing

Introduction

Participation in ultra-endurance competition is increasing in popularity. While abundant literature is available regarding marathon running, little is known about the effects on the human body of running hundreds or even thousands of kilometres in a single event (Raschka et al., 1991, Raschka & Plath 1992).

Marathon and ultra-marathon performance is associated with different problems such as variable decreases in body mass. A decrease in total body mass can be observed during ultra-endurance performance in ultra-running (Skenderi et al,. 2006), ultra-cycling (Bircher et al., 2006, Knechtle et al., 2005) and ultra-triathlon competition (Knechtle et al. 2008c, Knechtle et al. 2008d, Lehmann et al. 1995). Such decrease in total body mass is mainly a consequence of dehydration (Kao et al. 2008, Pastene et al. 1996, Whiting et al. 1984).

However, during longer performances, the decrease in total body mass also involves reduced fat mass (Knechtle et al., 2008d, Raschka et al., 1991, Ra-

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Authors submited their contribution of the article to the editorial board.
Accepted for pinting in Journal of Human Kinetics vol. 21/2009 on April 2009.

schka & Plath 1992). In few cases (Bircher et al. 2006, Knechtle et al., 2005) and field studies (Knechtle et al., 2007, Knechtle et al., 2008a), a decrease in skeletal muscle mass during ultra-endurance performance has also been measured. In reports about ultra-endurance, changes in body mass, fat mass and skeletal muscle mass were determined immediately post race.

In several studies, change in body water has been investigated during and after ultra-endurance performance (Fellmann et al., 1999, Knechtle et al., 2008c, Knechtle et al., 2008d). There has been little research to date regarding changes in body mass and body water in the recovery phase following ultra-endurance competition (Fellmann et al. 1989). In a single case study it was suggested that an increase in total body water during recovery following a triathlon might be a consequence of hypoproteinemic edemas (Knechtle et al., 2008c).

The purpose of this case study was to investigate changes in total body mass, body fat, skeletal muscle mass and total body water before, during and after ultra-endurance performance in a single Triple Iron Triathlon participant until complete recovery after the race.

Materials and Methods

The "Virginia Triple Iron Triathlon" is the longest ultra-endurance triathlon in North America with athletes having to cover 11.4 km swimming, 540 km cycling and 126.6 km running within 60 hours time limit. This race is considered to be the toughest triathlon in North America. The race started on October 4, 2007 at 07:00 am at Lake Anna State Park, Virginia, USA. The swimming event was in Lake Anna with a water temperature of 23 °Celsius. The athlete wore a wetsuit (sailfish one®) with 1.5 to 5 mm SCS Nanoskin Neoprene by Yamamoto. Athletes had to swim 12 laps of 950 m each. The cycling portion was on a hilly bike section in the park where drafting was prohibited. Athletes had to cycle after a short lap of 1.8 km a total of 69 laps of 7.8 km each with a total vertical change of 2,330 m in the whole cycling part. After cycling, the athletes had to run 39 laps on a hilly running course of 3.24 km after a short lap of 0.24 km with 660 m of altitude change in the whole run split. The racers were allowed to use as many clothes, bicycles and equipment as necessary. They had their own support crews of several members in order to help change clothes and equipment and to provide nutrition. The weather was mostly sunny, hot and humid. The temperature during the day rose to a maximum of 39 °Celsius and dropped to a low of 19 °Celsius in the night.

Our volunteer was a non-professional, well-experienced ultra-endurance triathlete (42 years old, 75 kg body mass, 178 cm body height, body mass index 23.6 kg/m2). He had eleven years of experience in ultra-endurance races (swimming, cycling and running) and had taken part in more than 50 ultra-triathlons over Double Iron and Triple Iron Triathlon distances in the past eleven years. His typical training hours per week ranged from 30 to 50 h with a total volume of 1,600 h per year. In the prior eleven years, he had swum 340 km, cycled 25,550 km and run 2,550 km on average per year. The athlete gave written informed consent for collecting data during the race according to the guidelines established by the Local Ethical Committee.

Before the race, a maximal exercise test was performed on a stationary cycle ergometer (Corival Cycle Ergometer, MedGraphics, St. Paul, Minnesota, USA) to assess maximum oxygen uptake (VO2max) in order to determine energy expenditure with the heart rate method during the race. The exercise protocol started at 100 Watts and was increased by 30 Watts every 3 minutes until volitional exhaustion. Using step testing, oxygen uptake (VO2) and carbon dioxide release (VCO2) were measured continuously (CPX Ultima, MedGraphics, St. Paul, Minnesota, USA). A portable heart rate monitor POLAR® S625X (POLAR Electro Oy, Kempele, Finland) was programmed with gender, age, body mass and the subject's VO2max in order to determine energy expenditure during exercise (Hiilloskorpi et al. 2003). Due to the fact that determination of energy expenditure during physical exercise with the POLAR® S625X starts at 90 beats per minute, we measured the resting metabolic rate using indirect calorimetry in order to determine total energy expenditure over 24 hours, with the energy expenditure during the recovery phase in addition to energy expenditure under load. The athlete was sitting on the cycle ergometer, at rest, while VO2 and VCO2 were continuously calculated from inspiratory oxygen concentration (%FIO2), expiratory oxygen concentration (%FEO2), expiratory carbon dioxide concentration (%FECO2) and ventilation (VE). VO2 and VCO2 were used for 5 min to calculate the oxidation rates of carbohydrate and fat.

The athlete prepared all his food before the race and took pre-packed food with him. Nutrition con-

sisted of commercial food that included a detailed description of its content on the package. Analysis of the energy content of non-commercial food was determined before the race. All food which the organizer supplied to the athlete during the race was continuously recorded. Food was weighed with an electronic balance (SOEHNLE mara, Soehnle, Murrhadt, Germany) and the energy content determined according to a food table (Kirchhoff 2002). After the race, energy intake was again recorded for the following six days. The water used for drinks was measured separately using a graduated jug. Excretion of urine was measured during and after the race with another graduated jug. The heart-rate monitor POLAR® S625X was programmed and used according to the manufacturer's instructions. Heart rate was continuously monitored during physical exercise with the POLAR® S625X and energy expenditure recorded.

All anthropometric and laboratory data were determined at the same time by the same investigator before the race, immediately after arriving at the finish line and then every 24 hours for 6 days until complete recovery as follows: Total body mass was measured to the nearest 0.1 kg. The circumferences of the extremities and the skin-fold thicknesses were determined in the same way on each occasion only on the right side, following Lee et al. (2000). The largest circumferences were measured on the upper arm as well as on the lower leg. On the thigh, the circumference was measured 20 cm above the superior pole of the patella. All measurements were repeated three times to the nearest 0.1 cm, and the average value recorded. The thicknesses of the skin-folds were measured likewise only on the right side, following Lee et al., (2000), using a skin-fold calliper (GPM skin-fold calliper, Siber & Hegner AG, Zurich, Switzerland). Measurements were taken of the chest (mid-axillary line, at the edge of the pectoralis major muscle, at the mid-level of the armpit), the flank (central axillary line, between the lower costal margin and the iliac crest), the abdomen (just right of the navel), the triceps (midway between the acromion and olecranon), the scapula (below the tip of the scapula), the calf (at the back of the knee) and the front thigh (20 cm above the patella). All measurements were repeated three times to the nearest 0.2 mm and the average value recorded. Besides the calculation of skeletal muscle mass and percent body fat by anthropometric measurements, percent total body water was measured using the bioelectrical impedance analyzer (BIA) model Tanita BC-545 (Tanita Corporation of America Inc., Arlington Heights, IL, USA) following Jebb et al. (2000). Urinary specific gravity was determined using Combur10 Test® (Roche Diagnostics, Mannheim, Germany). Capillary blood samples of 80 μl were taken from the finger tip and immediately analyzed using i-STAT® 1 System (Abbott Laboratories, Abbott Park, Illinois, USA) in order to determine hematocrit, plasma sodium and plasma urea.

To determine resting metabolic rate with the respiratory gases, the oxidation rates of fat and carbohydrate were calculated using the stochiometric equations of Frayn (1983). Energy expenditure from fat and carbohydrate was converted into kcal*min^{-1} by multiplying the oxidation rate of fat by 9.1 and the oxidation rate of carbohydrate by 4.2 using the Atwater general conversion factor (Atwater 1909). Skeletal muscle mass was calculated with the anthropometric method using the formula of Lee et al., (2000), and percent body fat was calculated according to Ball et al., (2004). Since skeletal muscle mass is directly determined in kg, fat mass was calculated with percent body fat and total body mass. Total body water in litres was calculated from percent total body water and total body mass. Changes in plasma volume were determined from the pre and post race hematocrit values according to Beaumont, (1972).

Table 1

Energy intake, energy expenditure and energy balance during and after the race (per day)

Time	Energy intake kJ [kcal]	Energy expenditure kJ [kcal]	Energy balance kJ [kcal]
During the race	65,942 [15,750]	114,969 [27,485]	– 49,027 [– 11,735]
1st day after the race	14,863 [3,550]	12,309 [2,940]	+ 2,553 [+ 610]
2nd day after the race	17,249 [4,120]	12,309 [2,940]	+ 4,940 [+ 1,180]
3rd day after the race	7,745 [1,850]	12,309 [2,940]	– 4,563 [– 1,090]
4th day after the race	9,797 [2,340]	12,309 [2,940]	– 2,512 [– 600]
5th day after the race	10,676 [2,550]	12,309 [2,940]	– 1,632 [– 390]
6th day after the race	11,178 [2,670]	12,309 [2,940]	– 1,130 [– 270]

Table 2

Change in body composition during and after the race

Time	Body mass (kg)	Skeletal muscle mass (kg)	Fat mass (kg)	Total body water (l)
Pre race	78.9	41.9	9.6	47.7
After race	77.8	43.3	9.2	49.4
1st day after the race	80.3	42.2	9.6	55.3
2nd day after the race	80.0	41.8	9.9	53.2
3rd day after the race	80.5	41.9	9.5	53.8
4th day after the race	80.1	42.1	9.9	52.2
5th day after the race	79.1	42.4	9.7	49.6
6th day after the race	76.8	41.3	8.9	47.1

Results

Pre race in the VO2max test, our athlete completed 370 Watt (4.93 Watt*kg^{-1}) and reached a VO2max of 59.0 ml*min^{-1}kg^{-1}. The anaerobic threshold was reached at 66 % VO2max. Resting metabolic rate was 2.04 kcal*min^{-1}, resulting in an estimated total daily energy expenditure of 12,309 kJ (2,937 kcal) at rest. Sixteen male and 3 female athletes started the race with 12 males and all female athletes finishing within the 60 hours. Our athlete finished the race in 1st position in a total time of 41:44:23 h:min:s setting a new course record. He invested 03:48:35 h:min:s in the swim portion, expending 14,297 kJ (3,415 kcal), 20:43:00 h:min:s in the bike split, expending 51,519 kJ (12,303 kcal), and 17:03:02 h:min:s in the run section expending 49,153 kJ (11,740 kcal). A total energy expenditure of 114,969 kJ (27,458 kcal) resulted while he ingested 65,942 kJ (15,750 kcal) during the race (Table 1). His total body mass was 78.9 kg at the start of the event, peaked at 80.5 kg 72 hours following the finish, and returned to baseline at 120 hours (Table 2). Six days after the race, total body mass was reduced by 2.1 kg. Fat mass calculated from anthropometric measurements was reduced by 0.7 kg on day 6 following the competition. Calculated skeletal muscle mass was increased by 1.4 kg immediately after the race and reached pre race value on day 3. Six days after the race, skeletal muscle mass was reduced by 0.6 kg compared to pre race. Total body water peaked 24 hours after the race and, returned to baseline on day 6. Hematocrit dropped from 48 % pre race to 42 % on day 1 after the race and returned to baseline on day 6. Plasma volume reached the highest value the first day after the race and returned to baseline on day 6. Plasma urea increased from 9.2 mmol*l^{-1} at baseline to 12.8 mmol*l^{-1} after the race. The highest value for urinary specific gravity was reached on day 1 after the race (Table 3). In total, he drank 29 l of fluids and excreted 16 l of urine during the race and in the following 6 days after the race. During the race and in the first 2 days after the race, he drank more than he excreted (Table 4). Pictures 1-5 show the development of edemas of his feet. Immediately after the race, no edemas were clinically visible (Picture 2). On day 2, the feet were clearly swollen (Picture 3) as well as on day 4 (Picture 4). Six days after the race, the edemas had practically disappeared (Picture 5).

Table 3

Laboratory parameters before, during and after the race

Time	Plasma sodium (mmol/l)	Hematocrit	Plasma urea (mmol/l)	Plasma volume (%)	Urinary specific gravity (g/ml)
Pre race	139	48	9.2	100	1.025
After race	137	44	12.81	117	1.025
1st day after the race	139	42	7.8	127	1.030
2nd day after the race	140	42	5.3	127	1.015
3rd day after the race	140	44	6.05	121	1.015
4th day after the race	139	43	6.7	122	1.015
5th day after the race	139	47	9.6	103	1.015
6th day after the race	139	48	9.9	100	1.015

Plasma volume was calculated as percentage of the pre race value.

Table 4

Fluid intake and urine output during the race and in the recovery phase (per 24 hours)

Time	Fluid intake (l)	Urine output (l)	Balance between fluid intake and urine output (l)
During the race	18.3	2.9	+ 15.4
1st day after the race	3.4	0.8	+ 2.6
2nd day after the race	2.7	1.6	+ 1.1
3rd day after the race	1.2	1.4	– 0.2
4th day after the race	1.0	3.4	– 2.4
5th day after the race	1.0	3.2	– 2.2
6th day after the race	1.4	3.0	– 1.6

Discussion

The loss in total body mass corresponds well with the 49,027 kJ (11,735 kcal) energy deficit. However, three days after arrival, total body mass had increased by 2.7 kg from 77.8 kg at the finish line to 80.5 kg. This change in total body mass must be due to a change in fluids. Parallel to the increase in total body mass, total body water increased by 4.4 l from 49.4 l to 53.8 l where also plasma volume increased. We presume that edemas must have developed in the skeletal muscle since calculated skeletal muscle mass was increased by 1.4 kg immediately post race. In addition, edemas of the lower limbs were clinically visible starting on day 2 after the race. We must therefore focus primarily on the fluid metabolism.

Bioelectrical impedance analysis showed an increase in total body water. We presume that the increase in plasma volume led to an increase in total body water and this resulted in subcutaneous edemas and therefore the skin-fold thickness increased at some regions of the body like the feet in the time course so that the determination of body fat with the anthropometrical method showed no changes throughout the race.

The retention of total body water could be the result of different mechanisms: Protein catabolism with hypoproteinemic edemas (Lehmann et al., 1995), increased protein synthesis with increased plasma volume (Maughan et al., 1985, Mischler et al., 2003), increase in plasma volume due to sodium retention (Fellmann et al., 1999) due to an increased activity of aldosterone (Wade et al., 1981) or dehydration and impaired renal function due to skeletal muscle damage (Uberoi et al., 1991).

Transient expansion in plasma volume is commonly reported after endurance events (Fellmann et al. 1999, Milledge et al. 1982). A possible explanation of the increase in total body water could be an increase in plasma volume due to sodium retention as a consequence of increased activity of aldosterone. An increase in total body water with an increase in plasma volume has been found by Fellmann et al. (1999) in a 7-day endurance race. They concluded that that the prolonged exercise induced a chronic hyperhydration at both the extracellular and intracellular level and that sodium retention was the major factor in the increase in plasma volume. However, in our athlete, plasma sodium remained rather unchanged at 139 mmol/l post race and presumably this mechanism was not responsible for the increase in total body water.

We found an increase in plasma urea after the race and an increase in skeletal muscle mass together with an increase in total body water and total body mass. Regarding the development of the increase in total body water and the edemas of the feet we have to look for a link between skeletal muscle damage and development of edemas. Milledge et al., (1982) found after a 5-day exercise period a constant plasma sodium concentration, a positive water balance, and a net movement of fluid from the intracellular to the extracellular space. In addition, they found a significant correlation between sodium retention and the increase in leg volume, suggesting that edemas may be the result of prolonged exercise. Presumably the development of edemas of the feet on day 2 is due to this mechanism. The expansion of the extracellular volume can lead to an increase in leg volume (Milledge et al. 1982) and clinically visible facial and ankle edemas might appear (Williams et al., 1979).

Total body water increased after the race continuously for 2 days and urinary specific gravity was decreased after the race. We have the situation of dehydration with decrease in total body mass and increased urinary specific gravity (Kavouras, 2002) but also an accumulation in total body water. Pre-

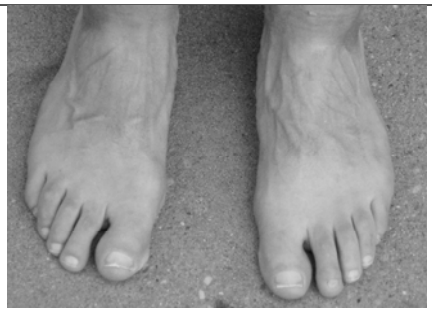

Fig. 1

Feet of the athlete pre race
The subcutaneous veins of the feet are clearly visible

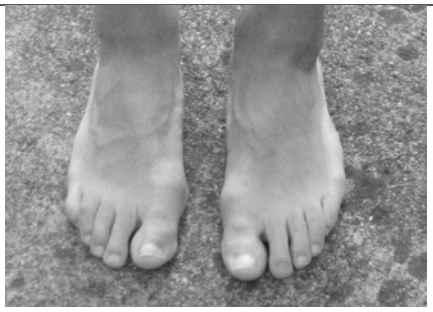

Fig. 2

Feet of the athlete after the finish of the race
The veins are still visible, but a little edemas have appeared

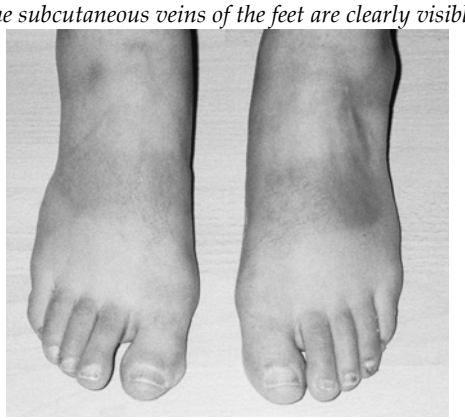

Fig. 3

Feet of the athlete 48 hours after the finish of the race
Edemas are clinically visible

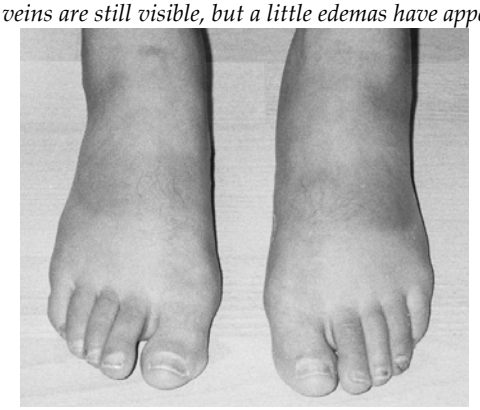

Fig. 4

Feet of the athlete 96 hours after the finish of the race
The edemas are still visible 4 days after arrival at the finish line

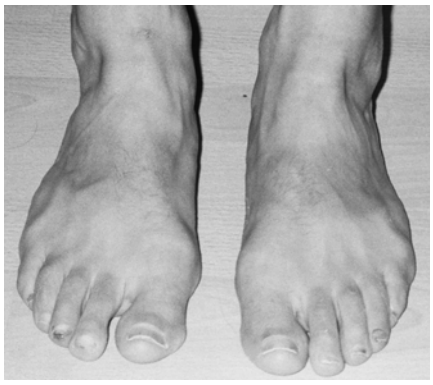

Fig. 5

Feet of the athlete 144 hours after the finish of the race
Six days after arrival at the finish line, the edemas have disappeared

sumably renal function was impaired during performance which caused a reduced excretion of water thus leading to an increase in total body water. Fluid intake during the race was remarkably higher than urine excretion. On day 4 after the race, however, urine excretion exceeded fluid intake. Six days after arriving at the finish line, total body water and plasma volume had reached about the starting value. We presume that the function of the kidney was impaired for about 3 days and it took another 3 days until all the water stored in the body was excreted.

Plasma urea as a parameter of protein degradation and impaired renal function (Irving et al. 1989) was increased after the race and we might think of skeletal muscle damage. In addition, the athlete complained about severe muscle pain and it took him 3 days to be able to walk again as he walked before the race. Fallon et al. (1999) found in a 1,600 km ultra-marathon an increase of urea and creatine kinase. The time course of increase of parameters indicating muscle damage may indicate that duration of running could be a determinant of such an increase. Also Janssen et al. (1989) and Reid & King

(2007) found and increase in urea after a marathon and an ultra-marathon.

The increase in total body water could also be the result of the impairment of the kidney due to the rhabdomyolyis occurring in ultra-endurance performance (Kim et al., 2007). In several studies, rhabodmyolysis during ultra-endurance running has been demonstrated (Skenderi et al., 2006, Uberoi et al., 1991) and an association between muscle damage and impaired renal function has been postulated. It is known from marathon running that the eccentric loads of long-term running may cause acute renal failure through dehydration, haemolysis and rhabdomyolysis (Irving et al., 1990). Under certain circumstances such as dehydration and heat stress (Neviackas & Bauer 1981), myoglobin can precipitate in the kidneys and hereby resulting in acute renal failure (Uberoi et al., 1991). Severe cases were considered to be the result of renal hypoperfusion aggravated by haemolysis and rhabodmyolysis due to a considerable amount of sports-specific, eccentric loads of running (Ounpuu 1990). The pathophysiology of acute renal failure is multifactorial and is the combined effect of rhabdomyolysis, dehydration, hypotension, nonsteroidal anti-inflammatory drugs and hyperuricemia (Uberoi et al. 1991). The duration of an ultra-endurance performance might be of importance. Already a 90 km run can lead to a transient oliguria (Irving et al., 1990). We had a positive fluid balance during the race and in the first 2 days, but from day 3 to day 6, excretion of urine was higher than fluid intake. Probably it took about 2 days until renal function started after the race.

We used in this field-study anthropometric methods (Ball et al. 2004, Lee et al. 2000) to determine solid masses and the bioelectrical impedance analysis (Jebb et al., 2000) to determine total body water. These methods had been investigated under stable laboratory conditions and compared to 'gold standards'. The determination of percent body fat by the anthropometric method was described in 2004 by Ball et al. (2004). They compared this method with DXA (dual energy X-ray absorptiometry) as 'gold standard' in males aged 18 to 62 years. Their conclusion was that this method was more accurately to determine percent body fat than recent anthropometric methods since the mean differences between percent body fat with DEXA and percent body fat with the anthropometric method ranged from 3.0 to 3.2%. Lee et al. (2000) developed in 2000 an anthropometric method to determine skeletal muscle mass in non-obese adults. Their 'gold standard' was whole-body multislice magnetic resonance imaging (MRI). There was a high correlation between anthropometrically determined skeletal muscle mass and MRI-measured skeletal muscle mass with $r2=0.83$ ($p<0.0001$).

The method of measuring total body water must be discussed in this context. Jebb et al. (2000) compared the Tanita device to determine total body water with the isotope dilution method as 'gold standard'. They concluded that the practical simplicity of the Tanita method was not associated with a clinically significant decrement in performance relative to a traditional impedance device. In recent ultra-endurance races, an increase in total body water has been demonstrated using bioelectrical impedance analysis (Fellmann et al. 1999, Knechtle et al. 2008b, Knechtle et al. 2008d); also with repetitive measurements during performance and recovery. This methodology may not provide valid estimates of total body water when hydration status is altered (O'Brien et al. 2002) since plasma osmolality and sodium concentration should be unchanged (Berneis & Keller 2000, Pialoux et al. 2004). Regarding our results, plasma sodium was unchanged pre compared to post examination and varied between 137 mmol/l to 140 mmol/l. Unfortunately, plasma osmolality was not determined in this investigation which is a limitation. To determine extra-cellular water, single frequency bioelectrical impedance analysis models do not accurately predict change in total body water (Gudivaka et al. 1999) and models with at least two frequencies (Segal et al. 1991) are needed. Tanita BC-545 has 2 different frequencies and is able to detect changes in extra-cellular body water. Due to the fact that plasma sodium was unchanged, we presume that the determination of total body water was reliable during this ultra-race.

Regarding the decrease in solid masses and the increase in total body water, the anthropometric method is possibly limited due to this increase in total body water where probably an edema in skeletal muscle mass has occurred as demonstrated with DXA in an ancient case study in a Triple Iron Triathlon (Knechtle et al., 2003b). The increase in total body water may also lead to an increase in adipose subcutaneous tissue thus leading to thickened skinfold thicknesses as shown in a case study during a Deca Iron Triathlon. The thickness of skin-folds was measured daily and an increase in total body mass (from 76.1 kg to 84.2 kg) and an increase in skin-fold

thickness at the thigh (from 5.8 mm to 15.8 mm) were found within the first 3 days (Knechtle et al., 2003a). Therefore, the anthropometric method with calculating skeletal muscle mass and fat mass might be limited in this actual situation.

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