Effects of a Deca Iron Triathlon on Body Composition – A Case Study

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Key words
- ultra-endurance
- metabolism
- water
- energy expenditure

Abstract

We investigated energy balance and change of body composition in one athlete in a multistage triathlon, the World Challenge Deca Iron Triathlon 2006, where athletes had to perform one Ironman triathlon of 3.8 km swimming, 180 km cycling and 42.195 km running per day for ten consecutive days. In one well-experienced male ultra-endurance triathlete, we measured body mass, skinfold thicknesses and perimeters of extremities, in order to calculate skeletal muscle mass, fat mass and percentage of body fat. Energy intake was measured by analysis of nutrition, and energy expenditure was calculated using a portable heart rate monitor. This was performed to quantify energy deficit. In addition, bio-impedance measurements were performed to determine fluid metabolism. The athlete finished the race in 128 hours, 22 minutes and 42 seconds in 3rd position. Body mass decreased by 1 kilogram, skeletal muscle mass decreased by 0.9 kilograms and calculated fat mass decreased by 0.8 kilograms. Total body water increased by 2.8 liters. Total energy expenditure for the Deca Iron was 89 112 kilocalories and a total energy deficit of 11 480 kilocalories resulted. We presume that energy deficit was covered by consumption of adipose subcutaneous tissue as well as skeletal muscle mass; the degradation of muscle mass seems to lead to hypoproteinemic edemas.

Introduction

It is well-known that fat is the main energy-rich substrate for long lasting exercise [13,28]. Long lasting exercise leads to a reduction of adipose subcutaneous tissue in laboratory [5] and field studies [26] due to the fact that fatty acids of adipose subcutaneous tissue are oxidized in the contracting skeletal muscle [30].

In ultra-endurance, it has been shown that athletes undergo, in some situations, an enormous energy deficit [4,16,18]. Ultra-endurance performance for hours or even days or weeks without breaks leads to a decrease in body mass [4,6,12,17, 18,22,26,28]. Body fat will be reduced [26] whereas skeletal muscle mass seems to be spared in long lasting endurance performance with breaks [28]. By contrast in multiday races with defined rests and breaks during the night, body mass remains stable [10,25] or even increases [36].

In ultra-endurance races without defined breaks during the nights, body mass decreases, and body fat as well as skeletal muscle mass also seems to decrease. In a 6-day run, a runner lost approximately 7 kg [17], at the Race across America, a cyclist suffered a loss of 5 kg body mass [18], and in another ultra-endurance cycling race, the same cyclist lost 2 kg of body mass, 0.79 kg of body fat mass and 1.21 kg of skeletal muscle mass [4].

In an Ironman triathlon, which by definition involves performing three different disciplines, we found one study about energy turnover. In the study of Kimber et al. [16], male Ironman triathletes expended, during one Ironman race, 42 018 ± 3897 kJ (10 036 ± 931 kcal) and ingested 16 495 ± 3634 kJ (3940 ± 868 kcal), so an energy deficit of – 25 007 ± 5333 kJ (– 5973 ± 1274 kcal) resulted. This deficit must be covered by degradation of the body's own energy stores.

In the present case study of a multistage triathlon race, which is over the distance of ten times an Ironman triathlon within ten consecutive days, we intended to see if an energy deficit occurs, and whether a change of body mass with a decrease of body fat and/or skeletal muscle mass is measurable. In addition, we tried to quantify the loss of body fat mass and the loss of skeletal muscle mass.

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Subject and Methods

Subject

Our subject was a nonprofessional, well-experienced ultra-endurance triathlete (42 years, 75 kg, 178 cm, BMI 23.6 kg/m^2). He had ten years of experience in ultra-endurance, and, until this actual race, had finished three Deca Iron triathlons. These were over 38 km swimming, 1800 km cycling and 422 km running. In addition, he had taken part in 50 ultra-triathlons over Double Iron triathlon and Triple Iron triathlon distances in the past ten years. His average training volume per week ranged from 30 to 50 h with a total volume of 1600 h per year. In the last ten years, he had swum 340 km per year, and cycled 25 550 km per year and run 2550 km on average. The athlete gave written informed consent for collecting data during the race.

Prerace laboratory exercise testing

One week before the race, a maximal exercise test was performed on a stationary cycle ergometer (Corival Cycle Ergometer, MedGraphics, St. Paul, MN, USA) to assess maximum oxygen uptake ($\dot{V}O_{2max}$). The exercise protocol started at 100 Watt and was increased by 30 Watt every 3 min until volitional exhaustion. During the step test, oxygen uptake ($\dot{V}O_2$) and carbon dioxide release ($\dot{V}CO_2$) were measured continuously (CPX Ultima, MedGraphics, St. Paul, MN, USA). In the $\dot{V}O_{2max}$ test, our athlete completed 370 Watt (4.93 $Watt \cdot kg^{-1}$) and reached a $\dot{V}O_{2max}$ of 59.0 $ml \cdot min^{-1} \cdot kg^{-1}$. Anaerobic threshold was at 66% $\dot{V}O_{2max}$. A portable heart rate monitor POLAR® S710 (POLAR Electro Oy, Kempele, Finland) was programmed with gender, age, body mass and the subject's $\dot{V}O_{2max}$ in order to determine energy expenditure (EE) during exercise [14]. Due to the fact that measurement of EE during physical exercise with the POLAR® S710 starts at 90 beats per minute (bpm), we measured the resting metabolic rate (RMR) using indirect calorimetry in order to determine total EE over 24 hours, with the EE during the recovery phase in addition to EE under load. The athlete was sitting on the cycle ergometer, at rest, while $\dot{V}O_2$ and $\dot{V}CO_2$ were continuously calculated from inspiratory oxygen concentration ($\%F_IO_2$), expiratory oxygen concentration ($\%F_EO_2$), expiratory carbon dioxide concentration ($\%F_ECO_2$) and ventilation ($\dot{V}_E$). $\dot{V}O_2$ and $\dot{V}CO_2$ were used for 5 min to calculate the oxidation rates of carbohydrate and fat. RMR was 2.04 $kcal \cdot min^{-1}$ (8.54 kJ), resulting in a total daily estimated EE of 2937 kcal (12 296 kJ) at rest.

Collection of data during the race

The athlete prepared all his food before the race and took prepacked food with him. Nutrition consisted mainly of commercial food with a detailed description of its content upon the package (Sportvital®, Cham, Switzerland). Analysis of the energy content of noncommercial food was determined before the race. All food which the organizer supplied to the athlete during the race was continuously recorded. The food was weighed with an electronic balance (SOEHNLE mara, Soehnle, Murrhadt, Germany) and energy content, according to the food table [9], determined. The water used for drinks was measured separately using a graduated jug. Heart rate was continuously monitored with the POLAR® S710, and EE recorded. The POLAR® S710 was programmed and used according to the manufacturer's instructions. Bio-impedance analysis was performed the evening before the start of the race, and after every Ironman triathlon just after arriving at the finish line. Before the start, and each day after finishing an Ironman distance, all anthropometric data was determined by the same investigator as follows: Body mass was measured with a commercial scale (Beurer BF 15, Beurer GmbH, Ulm, Germany) to the nearest 0.1 kg. The perimeters of the extremities and the skinfold thicknesses were determined in the same way on each occasion. The perimeters of the extremities were measured only on the right side, following Lee et al. [21]. The largest perimeters were measured on the upper arm as well as on the lower leg. On the thigh, the perimeter 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 thickness of the skinfolds were measured likewise only on the right side, following Lee et al. [21], using a skinfold calliper (GPM skinfold calliper, Siber and Hegner AG, Zurich, Switzerland). Measurement points were in the middle axillar line, the chest (at the edge of the musculus pectoralis major, on the medium height of the armpit), the flank (central axillar line, rib bow-crista iliaca), belly (right of the navel), the triceps (middle of acromion-olecranon), the scapula (below the head of the scapula), the calf (on the back of the knee) and finally the thigh (20 cm above the patella). All measurements were repeated three times to the nearest 0.2 mm and the average value recorded. Beside the calculation of skeletal muscle mass and body fat by anthropometric measurements, body fat, total body water, intracellular water and extracellular water were measured with a multiple-frequency bioelectrical impedance analyzer (MFBIA) model InBody 3.0 (Biospace, Seoul, Korea). InBody 3.0 has a tetra polar 8-point tactile electrode system performing at each session 20 impedance measurements by using 4 different frequencies (5 kHz, 50 kHz, 250 kHz, 500 kHz) at each five segments (right arm, left arm, trunk, right leg, left leg). The parameters body mass, lean body mass, total body water, intracellular water, extracellular water, fat mass, percent body fat, protein mass and mineral mass were directly measured. Bioelectrical impedance measurements were performed immediately after arriving at the finish line, with the subject standing in an upright position, barefoot, on foot-electrodes on the platform of the instrument, with the legs not touching the thighs, and the arms not touching the torso. The subject stood on the four foot-electrodes: two oval shape electrodes and two heel shaped electrodes, and gripped the two palm-and-thumb electrodes in order to yield two thumb electrodes and two palm electrodes. He did this without shoes or excess clothing. The skin and the electrodes were pre-cleaned and dried.

Calculations

To determine RMR with the respiratory gases, the oxidation rates of fat and carbohydrate were calculated using the stochiometric equations of Frayn [11], where oxidation of carbohydrates is given by the equation $4.55 \times \dot{V}CO_2 - 3.21 \times \dot{V}O_2 - 2.87\,n$ and the oxidation of fat is given by the equation $1.67 \times \dot{V}O_2 - 1.67 \times \dot{V}CO_2 - 1.92\,n$. According to the study of Romijn et al. [30], the nitrogen excretion rate (n) was assumed to be 135 $\mu g \cdot kg^{-1} \cdot min^{-1}$. Energy expenditure from fat and carbohydrate was converted into $kcal \cdot min^{-1}$ 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 [2]. Skeletal muscle mass (SM) and percent body fat (%BF) were calculated according to the following formula:

$$SM = Ht \times (0.00744 \times CAG^2 + 0.00088 \times CTG^2) + 0.00441 \times CCG^2 + 2.4 \times sex - 0.048 \times age + race + 7.8$$

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where Ht = height, CAG = skinfold corrected upper arm girth, CTG = skinfold corrected thigh girth, CCG = skinfold corrected calf girth, sex = 1 for male, race = 0 for white [21].

%BF was calculated using the following formula:

$$\%BF = 0.465 + 0.180\,(\Sigma 7SF) - 0.0\,002\,406\,(\Sigma 7SF)^2 + 0.0661\,(age)$$

where Σ7SF = the sum of skinfold thickness of chest, midaxillary, triceps, subscapular, abdomen, suprailiac and thigh mean [3]. Fat mass was calculated with %BF from body mass.

The race

The competition took place in the city of Monterrey in the Province of Nuevo León in the North of Mexico. Monterrey, the capital of Nuevo León, lies at 540 m above sea level and has more than one million inhabitants. Temperature in Monterrey varies from 16 °C to 28 °C in November, but it can fall as low as 10 °C and rise up to 34 °C and more. Usually there is no rain and only little wind. The "World Challenge Deca Iron Triathlon" started on November 6th 2006 and went on until November 15th 2006. Seventeen athletes (14 male, three female) from ten different countries and three continents entered the race. They had to perform, every day for ten continuous days, an Ironman triathlon of 3.8 km swimming, 180 km cycling and 42.195 km running. Every morning at 09:00 a.m. the swimming started in the 50-m outdoor pool, in the park of Sociedad Cuauhtemoc and Famosa in Monterrey, 3 km distance from the cycling and running tracks. The temperature of the water in the Olympic pool was between 17 °C and 21 °C (**Table 1**). Laps of 100 m were counted by personal lap counters. After having completed the swimming part, athletes were transferred by car to the Parque Niños Héroes, where they had to complete the cycling and running. The Parque Niños Héroes is a park closed to traffic, completely illuminated, and has a cycling track of asphalt, which is 95 % flat and has a slight hill on the remaining 5 % of the distance. For the cycling, athletes had to perform 94 laps of 1.915 km each. After changing to the run, athletes had to run first a short lap of 703 m and then 22 laps of 1.886 km. An altitude of 1650 m had to be climbed in each Ironman triathlon. Athletes had the possibility of being helped by their own support crew. Drafting during cycling was prohibited. Laps in the park were counted electronically. The weather conditions and the highest temperature during the day as well as pool water temperature are represented in **Table 1**. During the whole race, accommodations were offered in the Sport Village of the park, where athletes had a room with toilet and shower. For nutrition, the organizer offered a restaurant operating 24 hours a day, with spaghetti, rice, baked potatoes, meat with tomato sauce, bread, eggs, eggs with ham, eggs with beans, eggs with sausage, hot cakes, pastries, sandwiches, tacos, sausage, soups, hot dogs, hamburgers, chicken, fish, oatmeal, cereal, French toast, salad, vegetables, granola bars, cookies, marmalade, cereal, salt, sugar, butter, honey, banana, oranges, apple, orange juice, Powerade®, Coca Cola®, purified water, mineral water, tea, milk, and chocolate milk, strawberry milk and banana milk, vanilla cake with strawberries and pineapple and chocolate cake with coconut cream.

Table 1 Weather conditions during the race

Day	Temperature air (°C)	Temperature water (°C)	Weather
1	28.5	19	sun, little wind
2	28.8	19	sun, little wind
3	30.1	19	sun, little wind
4	34.9	20	sun, little wind
5	35.9	21	sun, little wind
6	20.3	17	clouds, moderate wind
7	22.1	17	clouds, little wind
8	25.7	18	sun, heavy wind
9	30.9	19	sun, moderate wind
10	23.9	19	sun, heavy wind

Results

Race performance

The athlete finished the race in 128 : 22 : 42 h : min : s in the 3rd position. The average time for one Ironman triathlon was 12 : 50 : 16 h : min : s. He performed his fastest Ironman race on day 1 (12 : 00 : 11 h : min : s.) and the slowest on day 4 (13 : 58 : 02 h : min : s). His average swimming time was 1 : 04 : 46 h : min : s (varying from 1 : 03 : 00 h : min : s on day 2 to 1 : 06 : 11 h : min : s on day 10), the average cycling time was 6 : 24 : 56 h : min : s (5 : 57 : 48 h : min : s on day 1 to 7 : 05 : 24 h : min : s on day 4) and the average time for running the marathon was 5 : 11 : 26 h : min : s (4 : 54 : 00 h : min : s on day 1 to 5 : 47 : 25 h : min : s on day 9). The total race time of our subject was 128 : 22 : 42 h : min : s, 3 h behind the winner, who finished in 125 : 31 : 05 h : min : s. The last official finisher completed the race in 213 : 56 : 43 h : min : s. The fastest overall time in swimming was 1 : 03 : 00 h : min : s, in cycling 5 : 32 : 01 h : min : s, in running 3 : 44 : 42 h : min : s and the fastest Ironman race time for all competitors was 11 : 11 : 06 h : min : s.

Intensity during performance

The athlete swam, cycled and ran, monitored by his heart rate monitor, and performed constantly with an average heart rate of 120 bpm to 125 bpm throughout the whole race. This corresponds to 56 % $\dot{V}O_{2max}$ to 61 % $\dot{V}O_{2max}$ according to his prerace $\dot{V}O_{2max}$ test. The energy expenditure – calculated from the results of the $\dot{V}O_{2max}$ test – at this intensity varied from 13 kcal · min^{-1} to 14 kcal · min^{-1} (54 kJ · min^{-1} to 59 kJ · min^{-1})

Energy expenditure (EE), energy intake (EI) and energy balance (EB) during the race

The athlete expended during the whole race – collecting data from the POLAR® S710 and including RMR during the night – a total energy of 373 094 kJ (89 112 kcal) with a daily EE of 31 585 ± 3822 kJ (7544 ± 913 kcal) per one Ironman triathlon (**Table 2**). During the race, total EI was 325 063 kJ (77 640 kcal) (**Table 3**). In the whole race, an energy deficit of 48 064 kJ (11 480 kcal) resulted. Only on day 3, 4, 6 and 7 a positive EB was found (**Table 4**).

Water metabolism

The athlete drank 11.3 l fluids per day (**Table 5**), total body water increased by 2.8 l, intracellular water by 2 l and extracellular water by 0.8 l (**Table 6**).

Table 2 Energy expenditure (EE) during the race and in 24 hours

Day	Swimming kJ [kcal]	Cycling kJ [kcal]	Running kJ [kcal]	Total EE in one Ironman triathlon kJ [kcal]	Total EE in 24 hours* kJ [kcal]
1	4245 [1014]	20800 [4968]	15541 [3712]	40586 [9694]	46733 [11162]
2	4237 [1012]	16583 [3961]	13527 [3231]	34348 [8204]	40264 [9617]
3	4119 [984]	14980 [3578]	13561 [3239]	32661 [7801]	38476 [9190]
4	3751 [896]	15332 [3662]	13778 [3291]	32862 [7849]	38003 [9077]
5	3156 [754]	17257 [4122]	8591 [2052]	29006 [6928]	34779 [8307]
6	3173 [758]	15821 [3779]	11882 [2838]	30877 [7375]	36931 [8821]
7	3165 [756]	16747 [4000]	10617 [2536]	30530 [7292]	36429 [8701]
8	3056 [730]	13615 [3252]	11815 [2822]	28486 [6804]	34239 [8178]
9	3006 [718]	13280 [3172]	11773 [2812]	28059 [6702]	33406 [7979]
10	2629 [628]	14042 [3354]	11769 [2811]	28440 [6793]	33812 [8076]
Total	34541 [8250]	158462 [37848]	122857 [29344]	315860 [75442]	373094 [89112]
Average ± SD	3454 ± 581 [825 ± 139]	15842 ± 2202 [3784 ± 526]	12284 ± 1921 [2934 ± 459]	31585 ± 3822 [7544 ± 913]	37308 ± 3994 [8911 ± 954]

* Including RMR during the recovery phase in the night

Table 3 Energy intake (EI) before, during and after an Ironman triathlon

Day	EI before an Ironman triathlon kJ [kcal]	EI during an Ironman triathlon kJ [kcal]	EI after an Ironman triathlon kJ [kcal]	Total EI in 24 hours kJ [kcal]
1	5233 [1250]	23948 [5720]	4396 [1050]	33578 [8020]
2	2135 [510]	24953 [5960]	5233 [1250]	32322 [7720]
3	5107 [1220]	26000 [6210]	7829 [1870]	38937 [9300]
4	2763 [660]	21394 [5110]	6740 [1610]	30898 [7380]
5	6573 [1570]	22734 [5430]	12476 [2980]	41784 [9980]
6	6322 [1510]	22064 [5270]	6322 [1510]	34289 [8190]
7	9545 [2280]	19719 [4710]	7033 [1680]	36299 [8670]
8	5275 [1260]	15784 [3770]	5233 [1250]	26293 [6280]
9	3391 [810]	15993 [3820]	5233 [1250]	24618 [5880]
10	5233 [1250]	15574 [3720]	4814 [1150]	25623 [6120]
Total	51581 [12320]	208167 [49720]	65314 [15600]	325063 [77640]
Average ± SD	5158 ± 2122 [1232 ± 507]	20816 ± 3893 [4972 ± 930]	6531 ± 2352 [1560 ± 562]	32506 ± 5761 [7764 ± 1376]

Table 4 Energy balance (EB) with energy intake (EI) and energy expenditure (EE) during the race

Day	EI kJ [kcal]	EE kJ [kcal]	EB kJ [kcal]
1	33578 [8020]	46724 [11160]	– 13184 [– 3149]
2	32322 [7720]	40277 [9620]	– 7954 [– 1900]
3	38937 [9300]	38476 [9190]	+ 460 [+ 110]
4	30898 [7380]	38016 [9080]	+ 7117 [+ 1700]
5	41784 [9980]	34792 [8310]	– 6991 [– 1670]
6	34708 [8290]	36927 [8820]	+ 2219 [+ 530]
7	36299 [8670]	36425 [8700]	+ 125 [+ 30]
8	26293 [6280]	34248 [8180]	– 7954 [– 1900]
9	24618 [5880]	33410 [7980]	– 8792 [– 2100]
10	25623 [6120]	33829 [8080]	– 8206 [– 1960]
Total	325063 [77640]	373127 [89120]	– 48064 [– 11480]
Average ± SD	32506 ± 5761 [7764 ± 1376]	3731 ± 3994 [8912 ± 954]	

Table 5 Fluid intake before, during and after the race

Day	Fluid intake the morning before an Ironman triathlon (l)	Fluid intake during an Ironman triathlon (l)	Fluid intake in the evening after an Ironman triathlon (l)	Total fluid intake in 24 hours (l)
1	1.4	7.5	2.5	11.4
2	1.5	10.25	2.8	14.55
3	1.6	6.8	3.5	11.9
4	2.0	6.5	3.1	11.6
5	2.1	8.75	4.5	15.35
6	2.2	6.15	2.5	10.85
7	2.2	5.5	2.8	10.5
8	2.0	4.5	2.1	8.6
9	1.7	5.5	3.2	10.4
10	2.3	4.15	1.3	7.75
Total	19	65.6	28.3	112.9
Average ± SD	1.9 ± 0.3	6.6 ± 1.9	2.8 ± 0.9	11.3 ± 2.3

Table 6 Water metabolism

Day	Total body water (l)	Intracellular water (l)	Extracellular water (l)
Prerace	49.6	33.6	16.0
1	52.1	35.6	16.5
2	54.7	37.0	17.6
3	53.0	35.4	17.7
4	52.4	35.0	17.4
5	52.8	35.2	17.6
6	52.1	35.2	16.8
7	53.9	36.7	17.3
8	53.1	36.0	17.2
9	52.7	35.5	17.2
10	52.4	35.6	16.8

Body mass and body composition

Body mass decreased 1 kg at the end of the race, calculated skeletal muscle mass decreased 0.9 kg and calculated body fat mass decreased 0.8 kg (▶ **Fig. 1**). Fat mass determined by anthropometry was 0.3 kg higher than fat mass determined with bioelectric impedance analysis (▶ **Table 7**). Skinfold thickness at the subscapular region decreased by 1.8 mm, at the belly by 3.6 mm, at the flank by 0.6 mm but increased at the calf by 3 mm (▶ **Fig. 2**). Perimeters of the extremities showed no changes (▶ **Fig. 3**).

Discussion

The main finding of our investigation was that a multiday race in the form of a Deca Iron triathlon with one Ironman triathlon per day for ten consecutive days resulted in a decrease of body mass of 1 kg from 79.3 kg to 78.3 kg, a decrease of 0.8 kg body fat mass from 8.2 kg to 7.4 kg and a decrease of skeletal muscle mass of 0.9 kg from 44.5 kg to 43.6 kg.

Energy deficit and decrease of body mass

Our athlete expended 31 585 ± 3822 kJ (7544 ± 913 kcal), on average, for one Ironman triathlon (▶ **Table 2**) and ingested 20 816 ± 3893 kJ (4972 ± 930 kcal) during one Ironman triathlon (▶ **Table 3**). In contrast to the results of Kimber et al. [16], their Ironman triathletes expended 42 018 ± 3898 kJ (10 036 ± 931 kcal) during one Ironman race and ingested 16 495 ± 3634 kJ (3940 ± 868 kcal), so that an energy deficit of – 25 007 ± 5333 kJ (– 5973 ± 1274 kcal) resulted. Their athletes expended more energy, consumed less energy and had a higher energy deficit than our athlete. The energy balance of our athlete varied from – 13 184 kJ (– 3149 kcal) on day 1 to + 7117 kJ (+ 1700 kcal) on day 4 (▶ **Table 4**). The total energy deficit of 48 064 kJ (11 480 kcal) (▶ **Table 4**) corresponds to the loss of 0.9 kg skeletal muscle mass and 0.8 kg body fat mass; an energy deficit of 5000 kcal (20 934 kJ) to 10 000 kcal (41 868 kJ) corresponds to about 1 kg of fat or 2 kg to 4 kg of muscle. Therefore we can say that the energy deficit is covered by the body's own stores of skeletal muscle mass, as well as body fat mass in about equal parts (▶ **Fig. 1**).

Decrease of body mass during endurance performance

In general, nonstop endurance races over hours and days result in a considerable decrease of several kg of body mass [4, 18, 22]. Our subject lost 1 kg of body mass during these ten Ironman triathlons (▶ **Fig. 1**). In general, body mass decreases significantly during one Ironman triathlon [20, 31, 32]. In one Ironman distance, body mass declines by 2.3 kg [20] to 2.5 kg [37]. A loss of 2.5 kg corresponds to a mean percentage loss in body mass of 3.1 % [35]. It must be hypothesized that the mass loss in an Ironman triathlon is mainly due to dehydration. Endurance performance leads to dehydration, which results in a mass loss [43]. But the body mass loss in an Ironman triathlon derives most likely from sources other than fluid loss [37]. During ultra-endurance performance, athletes lose mainly body fat. In a run over 1000 km in 20 days, fat mass and all skinfold thicknesses decreased. In men, fat mass at the start of the run was 10 kg and dropped to 7.7 kg at the end of the run. Skinfold thicknesses decreased throughout the run; at suprailiacal, skinfold thickness decreased by 0.34 cm, at subscapular by 0.16 cm, at triceps by 0.16 cm, at thigh by 0.09 cm and at the calf by 0.11 cm [26].

Loss of muscle mass and muscle protein during ultra-endurance exercise

Apart from fat mass, skeletal muscle mass also decreases in a ultra-endurance performance. In a run over 1000 km in 20 days, skeletal muscle mass initially increased, decreased in the middle of the distance, and then remained stable. As a result of the decreased skeletal muscle mass, all muscle perimeters are reduced

Table 7 Body mass, skeletal muscle mass and fat mass

Day	Body mass (kg)	Muscle mass* (kg)	Fat mass* (kg)	% body fat* (%)	Fat mass+ (kg)	% body fat+ (%)
Prerace	79.3	44.5	8.2	10.38	12.1	15.3
1	78.0	41.7	7.3	9.45	7.3	9.4
2	77.1	41.0	7.6	9.87	3.1	4.0
3	78.4	42.0	7.5	9.61	6.8	8.7
4	78.8	43.3	7.6	9.71	8.0	10.2
5	78.4	42.2	7.6	9.77	7.1	9.1
6	77.8	41.8	7.6	9.87	7.3	9.3
7	78.0	41.8	7.3	9.41	4.9	6.3
8	78.7	42.6	6.9	8.86	6.8	8.6
9	78.8	42.6	6.8	8.73	7.4	9.4
10	78.3	43.6	7.4	9.51	7.3	9.3
Average ± SD	78.3 ± 0.6	42.5 ± 1.0	7.4 ± 0.4	9.6 ± 0.5	7.1 ± 2.1	9.0 ± 2.7

* Determination by anthropometric measurement; + Determination by bioelectrical impedance measurement

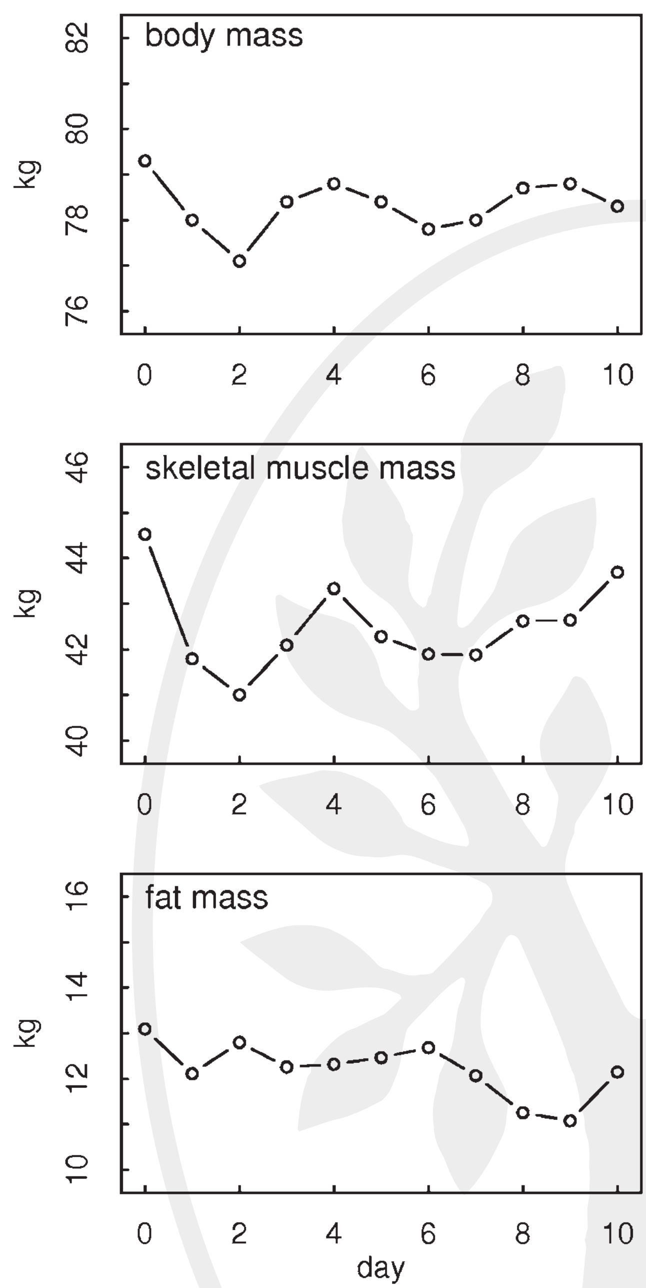

Fig. 1 Change of body mass, skeletal muscle mass and body fat mass during the competition.

with the exception of the thigh [27]. We assume that the energy deficit in our athlete was covered by degradation of subcutaneous adipose tissue, as well as skeletal muscle mass of the exercising limbs. This seems to be obvious at the leg. Skinfold thickness at the calf increased from 4 mm prerace to 7 mm on day 10 (**Fig. 2**) and the perimeter of the thigh decreased from 56.8 cm to 56.2 cm on day 10 (**Fig. 3**). We presume that the increase of skinfold thickness at the calf is a result of increased body water (**Table 6**) and the decrease of the perimeter of the thigh is a sign of degradation of muscle mass (**Fig. 1**), both leading to hypoproteinemic edemas of the lower limbs.

Ultra-endurance and edemas?

During long lasting physical activity, it is fundamental that protein of skeletal muscle mass is reduced besides the energy-rich substrates such as carbohydrates and fat. During very long endurance exercise, it has been shown that a continuous degradation of muscle protein [27,35] results in the reduction of the concentration of albumin and total protein [10,22,29]. During an ultra-endurance running race in Alaska, the athletes ingested mainly carbohydrates. They also lost body mass, and because this was associated with ketonuria and proteinuria, it was concluded that proteins were metabolized to support energy expenditure [6]. Edemas of the lower limbs are described in ultra-performance. Robertshaw and Swaminathan [29] mentioned in their study with 16 subjects in a 100-km hill walk that clinically detectable edemas appeared at the end of the walk. The duration or length of an ultra-endurance performance may be of importance whether edemas appear or not. Väänänen and Vihko [38] could find no signs of edemas in a 2-day 100-km ski event. Edemas may explain the increase of skinfold thickness in the calf with increasing duration of the race (**Fig. 2**). An increase of skinfold thickness was also shown in the study of Dressendorfer and Wade [10] where runners completed a 400-km road race in 15 days. In addition to the increase of skinfold thickness at the calf (**Fig. 2**), intracellular and extracellular water increased in our athlete (**Table 6**), as bioelectrical impedance measurements showed. These two observations demonstrate that an increase of body water (**Table 6**) and a decrease of skeletal muscle mass (**Fig. 1**) result in edemas at the ankles.

Edemas as a consequence of fluid overload?

Apart from degradation of skeletal muscle mass and developing edemas, fluid overload may also lead to edemas. Our athlete drank 6.6 ± 1.9 l fluids per Ironman triathlon (**Table 5**). With an average race time of approximately 13 h, the average fluid intake per hour lies at 500 ml, which is below the values of Speedy et al. [36,37] with about 700 ml per hour. We therefore conclude that our athlete suffered not from fluid overload.

Eccentric exercise and damage of skeletal muscle mass

During this race, our athlete had to run 422 km within ten days in addition to the swimming and cycling part. It is well-known from several studies that running as eccentric exercise leads to damage of skeletal muscle [33,34] depending upon the distance covered per time (km per week) rather than the intensity of the exercise [19]. The effect is a decrease of fiber size, as shown in the study of Sjöström et al. [29], where an ultra-runner covered 3529 km within seven weeks. The resulting muscle damage of ultra running may lead not only to a reduction of skeletal muscle mass, but also to an impairment of fat oxidation, since oxidative capacity becomes significantly reduced [15]. Running 600 km in an ultra-endurance run with 20 km every 16.5 h within 30 days leads to a significant decrease of the oxidative capacity of skeletal muscle [15]. We presume that muscle mass decreases faster and is more expressed than fat mass. As **Fig. 1** shows, calculated skeletal muscle mass decreased after the first day by 2.8 kg (– 2.6% body mass), whereas fat mass decreased less with 0.9 kg (– 0.9% body mass). In the following days, skeletal muscle mass remained low at 41 kg to 42 kg and increased by the end of the race to 43.6 kg.

The increase of skeletal muscle mass might be interpreted as a training effect. Also, Raschka et al. [27] could show that skeletal muscle mass increases during a multistage run.

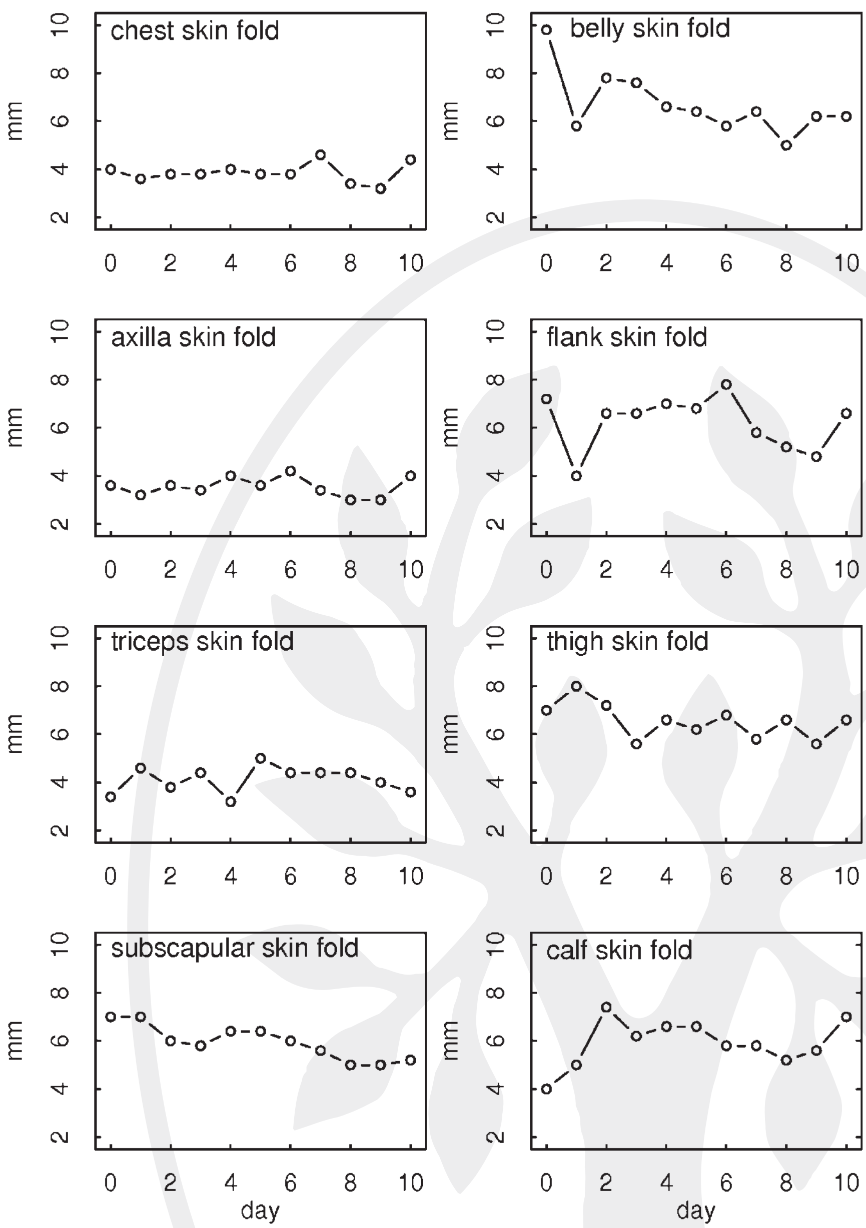

Fig. 2 Change of skinfold thicknesses during the competition.

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The effect of temperature and heat

Our subject from Europe travelled in the winter period to the tropical heat in Mexico and had to race in the heat (**Table 1**). Heat increases oxidative stress [24], impairs metabolism and performance [41,42] and reduces energy expenditure [44]. In addition, heat reduces $\dot{V}O_{2max}$ [1] and increases heart rate [41, 42]. Our athlete performed at a heart rate of 120 bpm to 125 bpm corresponding to 56% $\dot{V}O_{2max}$ to 61% $\dot{V}O_{2max}$ with an average energy expenditure of 13 kcal·min^{-1} to 14 kcal·min^{-1} according to the results of the prerace $\dot{V}O_{2max}$ test. With an average race time of 770 min per Ironman triathlon, we calculate an average energy expenditure of 10 000 kcal (41 868 kJ) per Ironman event. In the first four days, energy expenditure was between 9000 kcal (37 681 kJ) to 11 000 kcal (46 054 kJ) (**Table 2**) and dropped then to about 8000 kcal (33 494 kJ). Probably our athlete became acclimatized, because he raced every day at the same heart rate. The initially higher energy expenditure (**Table 2**) might be explained by an increased heart rate due to the high temperatures in Mexico (**Table 1**) compared to the low temperatures in Europe in November. And it is well-known that during field conditions, heart rate is influenced by several factors like emotion, high temperature, high humidity, dehydration and illness [8]. The cold temperature of the water (**Table 1**) during the 1-h swim in the morning seems to have had no effect on energy expenditure. Independent of the water temperature, energy expenditure (**Table 2**) decreased from day 1 with 1014 kcal (41 868 kJ) to day 10 with 628 kcal (2629 kJ) and swimming time increased constantly from 1 : 03 : 32 h : min : s from day 1 to 1 : 06 : 11 h : min : s on day 10.

Body composition assessment by bioelectrical impedance measurements and by anthropometry

We had the possibility to determine fat mass and percent body fat with anthropometry and with bioelectrical impedance measurements. With bioelectrical impedance measurement, fat mass was 0.3 kg lower (7.1 ± 2.1 kg compared with 7.4 ± 0.4 kg) and percent body fat 0.6% lower (9.0 ± 2.7% compared with 9.6 ± 0.5%) (**Table 7**). These results seem not to differ.

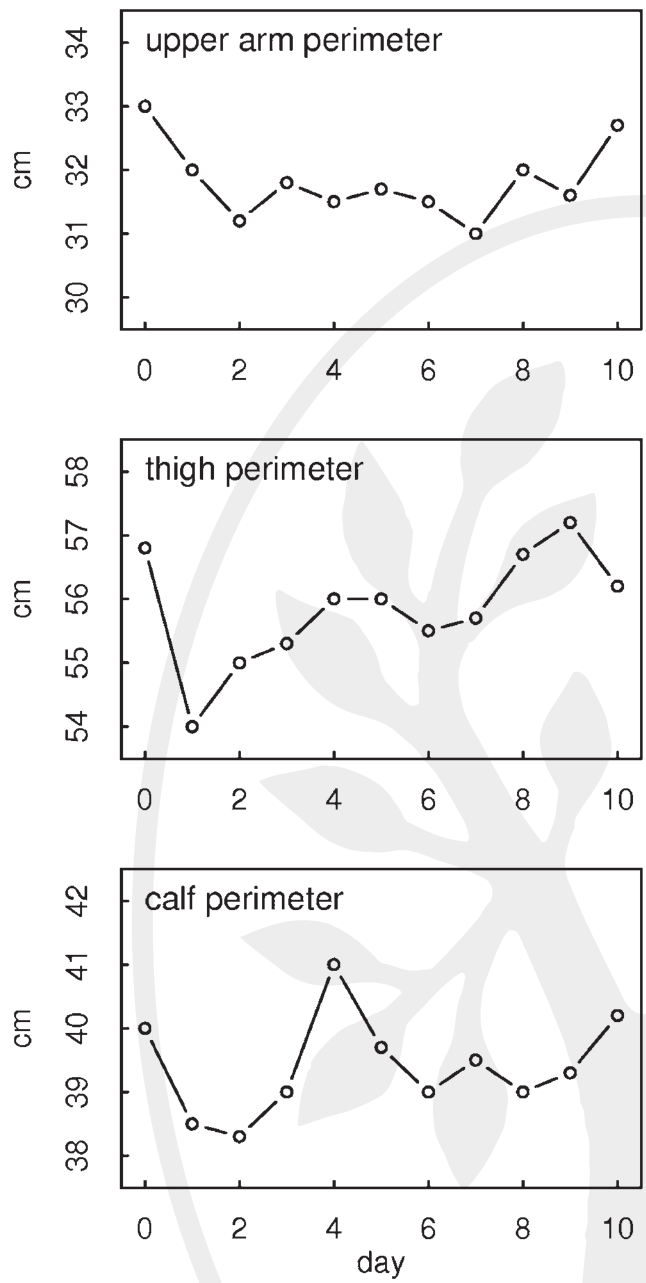

Fig. 3 Change of limb perimeters during the competition.

When determination of body mass and percent body fat (%BF) with bioelectrical impedance analysis (BIA) are compared with anthropometric measurements in athletes, BIA is reliable and a valid field measurement tool to measure body mass and %BF [23]. Both methods seem to be sufficiently accurate on the narrow sample of subjects on which they were developed [7], and both methods show a fairly good correlation with DEXA as a reference method [39].

Conclusions

A multistage triathlon with one Ironman triathlon per day over ten consecutive days in a well-trained and well-experienced athlete leads to a total energy deficit of 11 480 kcal (48 064 kJ), a decrease of 1 kg body mass with a loss of 0.9 kg skeletal muscle mass and 0.8 kg fat mass, and an increase of total body water of 2.8 l. We conclude that energy deficit was covered by consumption of adipose subcutaneous tissue, as well as skeletal muscle mass. The degradation of muscle mass seems to lead to hypoproteinemic edemas.

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