

Original Article

Male ironman triathletes lose skeletal muscle mass

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We investigated whether male triathletes in an Ironman triathlon lose body mass in the form of fat mass or skeletal muscle mass in a field study at the Ironman Switzerland in 27 male Caucasian non-professional Ironman triathletes. Pre- and post-race body mass, fat mass and skeletal muscle mass were determined. In addition, total body water, hematological and urinary parameters were measured in order to quantify hydration status. Body mass decreased by 1.8 kg ($p < 0.05$), skeletal muscle decreased by 1.0 kg ($p < 0.05$) whereas fat mass showed no changes. Urinary specific gravity, plasma urea and plasma volume increased ($p < 0.05$). Pre- to post-race change (Δ) in body mass was not associated with Δ skeletal muscle mass. Additionally, there was no association between Δ plasma urea and Δ skeletal muscle mass; Δ plasma volume was not associated with Δ total body water ($p > 0.05$). We concluded that male triathletes in an Ironman triathlon lose 1.8 kg of body mass and 1 kg of skeletal muscle mass, presumably due to a depletion of intramyocellular stored glycogen and lipids.

Key Words: body fat, body mass, dehydration, ultra-endurance, triathlon

INTRODUCTION

Ironman long-distance triathlons covering 3.8 km swimming, 180 km cycling and 42.2 km running are increasing in popularity. Each year more athletes are participating in these races in order to qualify for Ironman Hawaii.¹

Finishing an Ironman triathlon takes an enormous effort. Speedy *et al.*² have shown in an Ironman race that successful finishers lost 2.5 kg of total body mass, most likely from sources other than fluid loss. Kimber *et al.*³ found, in a further study, that male Ironman triathletes expended about 10,000 kcal per Ironman race and ingested about 4,000 kcal so that an energy deficit of around 6,000 kcal resulted during an Ironman triathlon. Since energy intake provided about 40 % of total energy expenditure, endogenous fuel stores were estimated to supply over half of the energy expended during an Ironman.

Probably this energy deficit cannot be covered by the degradation of intramyocellular energy stores. In ultra-endurance triathlons over the Triple Iron triathlon distance of 11.4 km swimming, 540 km cycling and 126.6 km running, athletes suffered a decrease in body mass consisting of fat mass and skeletal muscle mass.^{4,5} With regard to single disciplines, ultra-endurance swimmers suffer no decrease in fat mass and skeletal muscle mass⁶, ultra-cyclists show a decrease in fat mass⁷ and ultra-runners a decrease in skeletal muscle mass.⁸

The aim of this present investigation was therefore to quantify a loss of body mass in male Ironman triathletes. In the case of a measurable loss of body mass, we intended to quantify whether this loss consisted of a solid mass such as fat mass or skeletal muscle mass. Athletes in a Triple Iron triathlon faced a decrease in both fat mass and skeletal muscle mass.^{4,5} We hypothesized that Ironman triathletes will also suffer a decrease in both fat mass

and skeletal muscle mass. In both kinds of races, athletes cycle and run and should therefore also reduce both fat mass and skeletal muscle mass as has been shown in the single disciplines.⁶⁻⁸

MATERIALS AND METHODS

Subjects and race

The organiser of the Ironman Switzerland informed all participants by a separate newsletter, 3 months before the event, about the investigation. Forty male athletes volunteered to participate in our study and 30 entered the investigation. They all gave informed written consent. The study was approved by the Institutional Ethics Committee of St. Gallen, Switzerland. Twenty-seven male Caucasian non-professional Ironman triathletes with (mean and SD) 39.3 (9.2) years, 77.8 (9.9) kg body mass, 1.79 (0.07) m body height, and a body mass index of 24.3 (2.4) kg/m² out of our study group completed the race within the time limit. Three triathletes had to give up due of medical complications.

On the 24 June 2007, Ironman Switzerland took place in the heart of the city of Zurich, Switzerland. 1,950 Ironman triathletes started in the morning at 06:00 a.m. with an air temperature of 17 °Celsius and the water in Lake Zurich at 20 °Celsius. Relative humidity was 88 % at the start of the race, 43 % at noon and 41 % in the eve-

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ning. At the start, the sky was blue and became cloudy slowly during the afternoon and evening. The highest temperature, 25 °Celsius, was reached in the afternoon. The athletes had to swim 2 laps in the lake to cover the 3.8 km distance, and then had to cycle 3 laps of 60 km each, which was followed by running 4 laps of 10.5 km each. In the cycling part, the highest climb from Zurich (400 metres above sea level) was Forch (700 metres above sea level), while the running course was completely flat in the city of Zurich. Nutrition was provided during the cycling and running courses by the organisers.

Measurements and calculations

Before the start of the race, and immediately after arrival at the finish line, every participant underwent anthropometric measurements, bioelectrical impedance analysis and the collection of blood and urinary samples in order to determine body mass, skeletal muscle mass, fat mass and total body water. Samples of urine were collected for determination of urinary specific gravity in order to quantify hydration status. At the same time, blood plasma samples were taken to determine hematocrit, urea, sodium and plasma volume. Body mass was measured to the nearest 0.1 kg using an electronic balance (Beurer, Ulm, Germany). Skeletal muscle mass was calculated using the following anthropometric formula: Skeletal muscle mass = $Ht \times (0.00744 \times CAG^2 + 0.00088 \times CTG^2 + 0.00441 \times CCG^2) + 2.4 \times sex - 0.048 \times age + race + 7.8$, where Ht = height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 1 for male, race = 0 for white, according to Lee *et al.*⁹ This anthropometric method was evaluated using 189 non-obese subjects and cross-validated using MRI (magnetic resonance imaging) evaluation. Percentage of body fat was calculated using the following anthropometric formula: Percent body fat = $0.465 + 0.180(\Sigma 7SF) - 0.0002406(\Sigma 7SF)^2 + 0.0661(age)$, where $\Sigma 7SF$ = sum of skin-fold thickness of chest, midaxillary, triceps, sub scapular, abdomen, suprailiac and thigh mean, according to Ball *et al.*¹⁰ This formula was evaluated using 160 men aged 18 to 62 years old and cross-validated using DXA (dual energy X-ray absorptiometry). The mean differences between DXA percent body fat and calculated percent body fat ranged from 3.0 % to 3.2 %. Significant ($p < 0.01$) and high ($r > 0.90$) correlations existed between the anthropometric prediction equations and DXA. Circumference of upper arm was measured in the middle of the right upper arm to the nearest 0.1 cm; circumference of the right thigh was taken at the level where the skin-fold thickness of thigh was measured and circumference of the right calf was measured at the maximum circumference of the calf. The same investigator took all circumferences to ensure reliability of anthropometric measurements. Skin-fold data were obtained using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. Again, the same trained investigator took all measurements since inter-tester variability is a major source of error in skin-fold measurements. Intra-tester reliability check was conducted prior to this testing on 27 male runners. No significant difference between the two trials for the sum of 8 skin-folds was observed ($p > 0.05$).

The intra-class correlation was high at $r = 0.99$. The same investigator was also compared to another trained investigator to determine objectivity. No significant difference existed between testers ($p > 0.05$). The skin-fold measurements were taken once through for all 8 skin-folds and then repeated three times by the same investigator; the mean of the three times was then used for the analyses. The timing of when the skin-fold measurements were taken was standardised to ensure reliability and readings were performed after 4 s. Percent total body water was measured by using the bioelectrical impedance analysis balance Tanita BC-545 (Tanita Corporation of America, Arlington Heights, IL, USA). Prior to the race, intra-tester reliability of measuring percent total body water was performed with 28 male runners. The intra-class correlation was high at $r = 0.99$. Impedance measurements were performed with the athletes standing in an upright position, barefoot in running wear, on foot-electrodes located on the platform of the instrument, with the legs and thighs not touching and the arms not touching the torso. The subjects stood on the four foot-electrodes and gripped the two palm-and-thumb electrodes in order to yield two thumb and two palm electrodes. Body mass and skeletal muscle mass were determined in absolute values (kg). For comparison between parameters, absolute values were therefore calculated from percent body fat and percent total body water. Fat mass in kg was calculated using percent body fat and body mass, and total body water in litres was calculated from percent total body water and body mass. Blood samples were analysed using i-STAT[®] 1 System (Abbott Laboratories, Abbott Park, IL, USA). Urinary specific gravity was determined using UR-YXXON[®] 300 (Macherey-Nagel, Düren, Germany). Changes in plasma volume were determined from the pre and post race hematocrit values according to Beaumont.¹¹

Statistical analysis

Measured and calculated parameters were compared before and after the race. The one sample Wilcoxon signed rank test was used to check for significant changes before and after the race. A relationship between parameters with a significant change was investigated using correlation analysis. For all statistical tests, the significance level was set to 0.05. Bonferroni correction was used for multiple statistical pre/post comparisons of calculated anthropometric parameters and laboratory parameters.

RESULTS

Performance

A total of 1,643 starters finished within the time limit (16 % drop out rate), 10 % of our subjects did not finish. Our athletes finished the race within 11:36 h:min. The winner completed within 8:25 h:min.

Changes in body composition

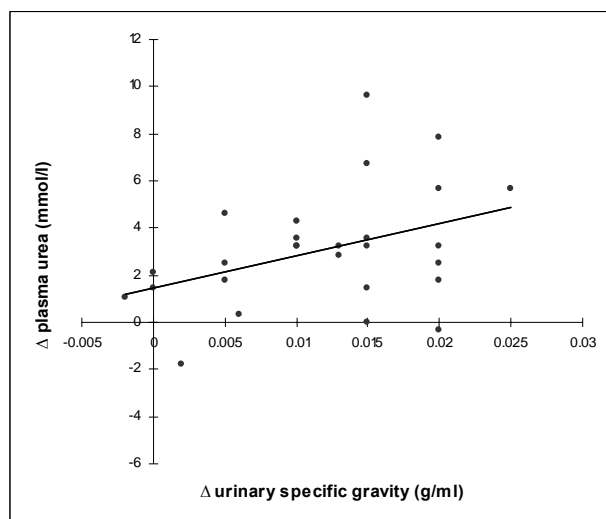
Body mass decreased significantly ($p < 0.05$) by 1.8 kg (Table 1). In parts, our athletes lost 1.0 kg of skeletal muscle mass ($p < 0.05$) and 0.5 kg of fat mass ($p > 0.05$). Pre- to post-race change (Δ) in body mass was neither associated with Δ skeletal muscle mass ($r = 0.11$, $p > 0.05$) nor with Δ fat mass ($r = 0.21$, $p > 0.05$). There was no significant association between total race time and the de-

Table 1. Mean values and standard deviation (SD) of solid masses for the 27 athletes.

	Pre-race	Post-race	Change (absolute)	Change (%)
Body mass (kg)	77.8 (9.9)	76.0 (9.7)	- 1.8 (1.2)*	- 2.3 (1.5)
Skeletal muscle mass (kg)	41.0 (4.7)	40.0 (4.2)	- 1.0 (1.1)*	- 2.3 (2.9)
Fat mass (kg)	11.6 (5.2)	11.1 (4.7)	- 0.5 (0.8)	- 3.6 (6.5)

* $p < 0.05$ **Table 2:** Mean values and standard deviation (SD) of laboratory and hydration status parameters before and after the race.

	Pre-race	Post-race	Change (absolute)	Change (%)
Hematocrit (%)	45.4 (3.0)	43.7 (3.2)	- 1.7 (2.8)*	- 3.6 (6.0)
Plasma urea (mmol/l)	5.7 (1.7)	8.7 (2.5)	+ 3.0 (2.5)*	+ 61.8 (50.7)
Plasma sodium (mmol/l)	139.2 (1.5)	138.6 (3.2)	- 0.6 (3.1)	- 0.4 (2.2)
Urinary specific gravity (g/ml)	1.010 (0.005)	1.022 (0.007)	+ 0.011 (0.007)*	+ 1.2 (0.7)
Total body water (l)	51.0 (5.9)	50.4 (5.9)	- 0.6 (2.1)	- 1.1 (5.2)

* $p < 0.05$ **Figure 1.** Δ Urinary specific gravity and Δ plasma urea were significantly correlated ($n=27$) ($r = 0.40$; $p < 0.05$).

crease in body mass, skeletal muscle mass or fat mass. Furthermore, no significant association between Δ body mass and Δ total body water could be demonstrated.

Changes in laboratory parameters

Both urinary specific gravity and plasma urea concentration increased significantly ($p < 0.05$); plasma sodium did not change ($p > 0.05$) (Table 2). The change in urinary specific gravity and Δ plasma urea were correlated ($r = 0.40$, $p < 0.05$) (Figure 1). Plasma volume increased significantly by 7.8 (12.6) % ($p < 0.05$). There was no association between Δ plasma urea and Δ skeletal muscle mass ($r = 0.20$, $p > 0.05$) and Δ plasma volume was not significantly associated with Δ total body water ($r = 0.16$, $p > 0.05$).

DISCUSSION

In these male Ironman triathletes, body mass decreased significantly by 1.8 kg and skeletal muscle mass decreased significantly by 1.0 kg, whereas fat mass showed no changes. Since there was no association between Δ plasma urea and Δ skeletal muscle mass, we presume that

no substantial degradation of myofibrillar proteins must have occurred, and the calculated loss in skeletal muscle mass might be due to depletion of intramyocellular stored energy, such as muscle glycogen and intramyocellular lipids.

Changes in body composition

In general, in an Ironman triathlon, body mass decreases significantly.¹²⁻¹⁴ Median weight change during the race ranges from 2.3 kg¹⁵ to 3.7 kg.¹⁶ A loss of 2.5 kg total body mass corresponds to a mean percentage loss in total body mass of 3.1 %.¹⁷ Our athletes showed a loss of 1.8 kg in body mass, corresponding to 2.3 % body mass, which is lower than the results in the above mentioned studies.^{2,15,16} As Speedy *et al.* have already assumed, the loss in body mass during such an Ironman must derive from solid masses and not from fluid loss.² Recent studies have already demonstrated that other factors, including oxidation of body fat and glycogen stores as well as the release of water stored with muscle and liver glycogen, may contribute substantially to changes in body mass

during prolonged exercise.^{18,19} This loss in body mass could account for up to 2 kg.¹⁸

In general during ultra-endurance performances over and beyond the marathon-distance, the decrease in body mass is thought to be due to dehydration.^{18,20,21} However, ultra-endurance performance can also lead to a reduction in fat mass^{4,22,23} and skeletal muscle mass.^{5,8,24} We found a significant reduction in skeletal muscle mass of 1.0 kg ($p = 0.0003$, 95% CI 0.60-1.43) (Table 1). The question remains as to whether our triathletes suffered a decrease in skeletal muscle mass in the form of contractile proteins or rather a decrease and depletion of the energy rich substrates stored in the muscle fibres. We presume that our triathletes did not suffer a substantial loss of myofibrillar protein since Δ plasma urea and Δ skeletal muscle mass showed no association and Δ body mass was not associated with Δ skeletal muscle mass. In the case of a positive association we would have hypothesised substantial damage of myofibrillar proteins with a reduction in skeletal muscle mass, since an increase in plasma urea is associated with skeletal muscle damage in ultra-triathlons.^{25,26}

However, plasma urea could also be increased due to impaired renal function as a result of dehydration, as shown with the association of the increase in urinary specific gravity with the increase in plasma urea (Figure 1). We rather think that the decrease in skeletal muscle mass was the result of degradation of the intramyocellular stored energy-rich substrates. Although endurance athletes rely more on intramyocellular lipids during endurance performances,^{27,28} muscular glycogen also gets depleted during endurance exercise.²⁹

Changes in laboratory parameters

Plasma volume increased by 7.8 (12.6) % ($p < 0.05$). The expansion in plasma volume – despite a loss in body mass – is documented in athletes competing in prolonged endurance events beyond the standard marathon distance.^{25,30} At or below this distance, however, plasma volume generally declines in greater proportion to body mass loss.^{21,31,32} These disparate findings may be explained by a difference in performance intensity. In this present investigation, Δ plasma volume was not associated with total race time ($p > 0.05$). Our triathletes developed a decrease in body mass and an increase in urinary specific gravity and were by definition dehydrated.³³ Although there is no ‘gold standard’ for assessment of hydration status, it appears that changes in body weight, along with urine osmolality, urinary specific gravity, conductivity and colour of urine are among the most widely used indices.³³

In marathon and ultra-marathon running, a decrease in body mass occurs as well as a decrease in plasma volume.^{31,32,34} This can be interpreted as dehydration.³⁵ However, plasma volume seems to behave differently after longer distances. After an Ironman triathlon, plasma volume increases.^{2,12} The expansion in plasma volume in ultra-endurance events may be explained by a protein shift to the intravascular space and by renal sodium retention.¹⁸ An increase in plasma volume in ultra-endurance performances leads to a decrease in hemoglobin and hematocrit post-exercise. An exercise-induced reduction in renal blood flow can be considered to be the underlying mechanism of an impaired renal function.³⁶⁻³⁸ In a Double

Iron triathlon, plasma volume increased by 15 %.^{25,26} Gastmann *et al.* concluded that the increase in plasma volume – with regard to the increase in plasma urea – seems to be related to a suppressed renal function with diminished renal blood flow, a decreased glomerular filtration rate and an increased hyperaldosteronemia-related renal sodium re-uptake, as well as to proteolysis during prolonged exercise.²⁵ Probably our athletes also developed an impairment of their renal function with an associated increase in urinary specific gravity and plasma urea (Figure 1) since Δ plasma urea was not associated with Δ skeletal muscle mass.

Limitations of the applied methods and implications for future research directions

Calculated skeletal muscle mass decreased significantly in the whole sample, however, in 4 subjects, skeletal muscle mass increased between 0.2 and 2.6 kg. We must be aware that the application of the anthropometric method in order to determine skeletal muscle mass might be limited in this special situation. In a study in ultra-endurance triathletes,⁵ skin-fold thicknesses decreased significantly after a Triple Iron triathlon in the upper body, but not in the lower body. Ultra-running leads to an increase in body water²¹ and this may explain an increase in leg volume³⁰ with a thickened skin-fold at the lower limb. The unchanged skin-fold thickness at the thigh and calf in the mentioned ultra-triathletes may lead to falsely high skin fold thicknesses. Furthermore, the change in ambient temperature between pre- and post-race might affect skin temperature and therefore influence estimation of total body water using bioelectrical impedance analysis.³⁹ An Ironman triathlon can, indeed, lead to skeletal muscle damage. Creatine kinase and cytokines increased after a long distance triathlon⁴⁰ as well as myoglobin⁴¹ are markers of skeletal muscle damage. In future studies, the change in body composition might better be determined using dual-energy x-ray absorptiometry and the change in intramyocellular energy stores might be measured using magnetic resonance spectroscopy. The isotope dilutional method would be more suitable to determine total body water turnover and markers of skeletal muscle damage and inflammation such as creatine kinase, myoglobin and cytokines could be measured in order to quantify skeletal muscle damage.

CONCLUSION

An Ironman Triathlon leads to a significant decrease in body mass and a significant decrease in skeletal muscle mass in male triathletes. The decrease in body mass was not associated with the decreased skeletal muscle mass, and the decrease in skeletal muscle mass was not related to the increase in plasma urea. We presume that the decrease in skeletal muscle mass was as a result of the depletion of the intramyocellular glycogen and triglyceride stores rather than due to damage in the skeletal muscle mass. In future studies, the changes in intramyocellular energy rich stores during an Ironman triathlon should be quantified non-invasively using nuclear magnetic resonance spectroscopy. Skeletal muscle damage might be quantified by measuring adequate markers of skeletal muscle damage and inflammation.

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AUTHOR DISCLOSURES

The authors have no conflict of interest and received no external funding.

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Original Article

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鐵人三項男選手流失骨骼肌質量

本篇研究調查，在瑞士鐵人競賽中，27 名非職業的鐵人三項白人男性運動員，其身體質量在競賽中，是以脂肪或以骨骼肌的形式流失。賽前和賽後的總身體質量、脂肪質量及骨骼肌質量被測量或計算。此外，為了定量身體水合狀態，總身體水份、血液及尿液指標也被測量。結果，總身體質量減少 1.8 公斤 ($p < 0.05$)，骨骼肌減少 1.0 公斤 ($p < 0.05$)，然而脂肪質量則沒有改變 ($p > 0.05$)。尿液比重，血漿尿素及血漿容積增加 ($p < 0.05$)。賽前和賽後的總身體質量改變和骨骼肌質量的改變不相關 ($p > 0.05$)。此外，血漿中尿素改變和骨骼肌質量改變無關 ($p > 0.05$)。血漿容積的改變和總身體含水量的改變亦無相關 ($p > 0.05$)。結論是，在該鐵人三項競賽中的男性運動員，總身體質量降低了 1.8 公斤而其中骨骼肌減少了 1.0 公斤，推定可能是因肌細胞內的肝醣和脂質的耗損而導致的。

關鍵字：體脂肪、身體質量、脫水、超耐力、鐵人三項