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Case report

EFFECTS OF AN EXTREME ENDURANCE RACE ON ENERGY BALANCE AND BODY COMPOSITION - A CASE STUDY

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ABSTRACT

The aim of this case study was to examine energy expenditure (EE) in one cyclist during an extreme endurance cycling race – the "XXAlps 2004" (2,272 km distance and 55,455 m altitude) which was completed in 5 days and 7 hours – and whether the energy deficit derives primarily from the degradation of subcutaneous adipose tissue or loss of muscle mass. Energy intake (EI) was continuously recorded. EE was estimated using two different methods: 1) Continuous heart rate recording using a portable heart rate monitor (POLAR® S710) and 2) using the individual relationship between heart rate and oxygen uptake (VO_2) determined under laboratory conditions. Body composition was assessed by measuring body mass, skinfold thickness and extremity circumferences. The cyclist lost 2.0 kg body mass, corresponding to 11,950 kcal (50 MJ). Fat mass was reduced by 790 g (7,110 kcal; 30 MJ) and fat free mass by 1.21 kg (4,840 kcal; 20 MJ). Circumferences of the lower extremities were reduced, in contrast skinfold thickness at the lower limbs increased. Energy deficit (ED) was calculated as the difference between EI and EE. Energy deficit using continuous heart rate monitoring was 29,554 kcal (124 MJ), and using the individual relationship between heart rate and VO_2 was 7,111 kcal (30 MJ). The results show that the difference between ED due to decreased body mass and ED estimated from continuous heart rate monitoring was 74 MJ (124 MJ – 50 MJ). In contrast the difference between ED due to decreased body mass and ED estimated from laboratory data was 20 MJ (30 – 50 MJ). This difference between methodologies cannot properly be explained. Body mass and skinfold thickness may be overestimated due to hypoproteinemic oedemas during endurance exercise. Data from the present study suggests the individual relationship between heart rate and VO_2 may provide a closer estimation of EE during extreme endurance exercise compared with corresponding data derived from continuous heart rate monitoring using the POLAR® S710.

KEY WORDS: Extreme endurance, cycling, heart rate monitoring, energy expenditure .

INTRODUCTION

It is well known that during long-lasting exercise of moderate intensity, mostly body fat is oxidised (Krogh and Lindhard, 1920). Generally, during very long lasting endurance exercise, energy derives mainly from subcutaneous adipose tissue (Raschka and Plath, 1992; Reynolds et al., 1999). Usually a reduction of the fat mass is observed, while the muscle mass generally remains constant (Raschka and Plath, 1992).

Thus, during long periods of exercise, lasting several hours, through to ultra-endurance competitions lasting several days, there may be a pronounced reduction of the subcutaneous fat. The data from the existing literature is not consistent and even partly contradictory. A reduction of the fat mass has not been confirmed during a long lasting endurance event such as a 24 hours cycling race (Knechtle et al., 2003a), a Triple Ultra Triathlon (Knechtle et al., 2003b) or a triathlon over 10 times an Ironman distance (Knechtle and Marchand, 2003). In the latter races (Knechtle et al., 2003a; 2003b; Knechtle and Marchand, 2003) cycling was the relevant component of the exercise, whereas in the initially mentioned work (Raschka and Plath, 1992; Reynolds et al., 1999) running was the predominant exercise.

We would expect there to be a difference in the reduction of subcutaneous adipose tissue between these alternative modes of exercise. In two recently published laboratory studies it has been shown that during running, more fat is oxidised than during cycling (Achten et al., 2003; Knechtle et al., 2004).

In some situations, the body mass of extreme endurance athletes has increased (Dressendorfer and Wade, 1991; Knechtle et al., 2003a; 2003b; Knechtle and Marchand, 2003), but in most reports it is decreased (Case et al., 1995; Colombani et al., 2002; Knechtle and Bircher, 2005; Knechtle et al., 2005; Nagel et al., 1989; Raschka and Plath, 1992).

Usually, during extreme endurance events lasting several days, an energy deficit results (Knechtle et al., 2003c; 2005; Knechtle and Bircher, 2005). In a 6-day- run we determined that a runner lost approximately 7 kg of fat mass, although the body weight decreased only by approximately 3 kg. With an energy intake of 39,660 kcal (166 MJ) and an energy expenditure of 54,076 kcal (226 MJ), an energy deficit of 14,410 kcal (60 MJ) resulted (Knechtle and Bircher, 2005). At the RAAM (Race Across America, 2003) the same athlete suffered an energy deficit of 83,526 kcal (350 MJ) and lost 5 kg body weight. It was not determined, how much fat or muscle mass the athlete lost (Knechtle et al., 2005).

In the present case study we wanted to examine whether the energy deficit derived primarily from the degradation of subcutaneous adipose tissue or from the degradation of muscle mass.

CASE REPORT

Subject

Our subject was a non-professional well-experienced extreme endurance cyclist (age; 34 years, height; 1.79 m, body mass; 68 kg). He finished the RAAM in 2003 and has won several 24 hours cycling races during the last few years. The athlete gave written informed consent for collecting data during the race.

Pre-race laboratory exercise testing

One month before the race, a maximal exercise test was performed on a stationary cycle ergometer (ergoline 900®, ergoline, Bitz, Germany) to assess VO_2peak. The exercise protocol started at 100 Watts (W) and was increased by 30 W every 3 minutes until volitional exhaustion. Lactate threshold was determined according to Coyle and co-workers (1983). Lactate threshold was identified as the VO_2 at which lactate increased 0.5 mmol · L^{-1} above baseline. During exercise, oxygen uptake (VO_2) and production of carbon dioxide (VCO_2) were measured continuously (Oxycon Pro, Jaeger, Würzburg, Germany).

Determination of energy expenditure (EE)

A portable heart rate monitor POLAR® S710 (POLAR Electro Oy, Kempele, Finland) was programmed with gender, age, body mass and the subject's VO_2max in order to determine energy expenditure (EE) during exercise (Hiilloskorpi et al., 2003).

Due to the fact that measurement of EE during exercise with the POLAR® S710 starts at 90 b·min^{-1}, we measured the resting metabolic rate (RMR) using indirect calorimetry. The athlete was sitting on the cycle ergometer, at rest. VO_2 and VCO_2were continuously calculated from inspiratory oxygen concentration (%F_IO_2), expiratory oxygen concentration (%F_EO_2), expiratory carbon dioxide concentration (%F_ECO_2) and ventilation (V_E). VO_2 and VCO_2were used for 10 min to calculate the oxidation rates of carbohydrate and fat. The oxidation rate of fat and carbohydrate was calculated using the stochiometric equations of Frayn (1983), where oxidation of carbohydrates is given by the equation $4.55 \times VCO_2 - 3.21 \times VO_2 - 2.87$ n and the oxidation of fat is given by the equation $1.67 \times VO_2 - 1.67 \times VCO_2 - 1.92$ n. According to the study of Romijn and co-workers (1993), the nitrogen excretion rate (n) was assumed to be 135 µg·kg^{-1}·min^{-1}. EE from fat and carbohydrate were 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 (1909).

In addition to the method of heart-rate based measurement of EE using the POLAR® S710, we established the individual relationship between heart rate and oxygen uptake (VO_2) during laboratory testing (Table 1).

Data collection during the race

The athlete prepared all his food before the race and took the pre-packed food with him. Nutrition consisted mainly of commercial food with a detailed description of its content upon the packing (E. C. Robins Switzerland GmbH, Cham, Switzerland). Analysis of the energy content of non-commercial food items was determined before the race (Der kleine Souci-Fachmann-Kraut, 1991). The energy content of all food (commercial and non-commercial) supplied to the athlete during the race was recorded on a daily basis.

All food supplied to the athlete during the race was continuously recorded. The water used for drinks was measured separately using a graduated jug. The excretion of urine was measured using a different measuring 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).

Blood laboratory examinations

Blood samples were collected immediately before the race (one hour before the start), immediately after the race (after crossing the finish line) and 5 weeks after the race. Specimens were stored on ice and transported to a Medical Laboratory (Institut Dr. Risch, Medizinische Laboratorien, FL-Schaan), where they were analysed during daily routine analyses.

Anthropometric data

Before the start, during the race - every 24 hours, and finally after the race, a physician determined body mass with a mechanical beam balance. The circumferences of the extremities and the skin fold thickness were always determined by the same individual, in the same way on each occasion. The circumferences of the extremities were measured only on the right side, since, when cycling, both body sides are symmetrically loaded. The largest circumferences were always measured on the forearm and on the upper arm as well as on the lower leg. On the thigh, the circumference was measured 15 cm above the superior pole of the patella. All measurements were repeated three times, and the average value recorded. The thickness of the skin fold was measured likewise only on the right side using a skin fold caliper (GPM skin fold caliper, Siber & Hegner AG, Zurich, Switzerland).

Measurement points were the cheek (underneath the temple at the height of the nostrils), the chin (at the beginning of the neck, at the centre of the chin), the chest (at the edge of the musculus pectoralis major, on the medium height of the armpit), the flank (central axiliar 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 knee (directly above the patella). All measurements were repeated three times and the average value recorded. From this the proportion of body fat was calculated (Jackson and Pollock, 1985). At day 2 and day 5, the support crew was too busy to take these measurements, therefore they are not reported.

The race

The ultracycling race XXAlps started on August 30th 2004. In a total distance of 2,272 km, with 55,455 meters of altitude, 49 passes had to be crossed. Seven ultracyclists entered the race and six athletes finished within the time limit of seven days. During the first two days, ambient temperature was between 15 to 30° Celsius during the day and 5 to 18° Celsius during the night. On days three and four bad weather conditions with heavy rain and harsh wind prevailed. The temperature during the rain was not higher than 15 degrees Celsius. Day three and day six were accompanied by heavy wind. On top of the "Col d'Izoard" in France there was heavy snowfall and temperature fell below 0° Celsius. Due to these weather conditions, the cyclist had to change clothes very often. The highest pass, the "Col de la Bonette" which is 2,805 meters above sea level was passed at temperatures between 20 to 25 ° Celsius. The cyclist suffered in the first day from a tense neck. On the second day, pain in the left knee arose. The pain was alleviated with gel, ointment and a warming pouch. The cyclist finished the race in 2nd position after five days, seven hours and 15 minutes, three hours behind the winner.

He completed 470 ± 72.9 km (372 - 541 km) per day with 2,582 ± 1,576 m (683 – 5,047 m) of altitude. During the whole race he slept 5 hours and rested 8 hours in order to eat.

RESULTS

Laboratory testing before the race

In the VO_2max test, our athlete completed 400 Watts ($5.89\ W{\cdot}kg^{-1}$) and reached a VO_2max of $61.1\ mL{\cdot}min^{-1}{\cdot}kg^{-1}$. Lactate threshold was at 77 % VO_2max. RMR was $2.53\ kcal{\cdot}min^{-1}$, resulting in a total daily estimated EE of 3,647 kcal (15.3 MJ). The individual relationship between heart rate and oxygen uptake (VO_2) determined during the VO_2max test is shown in Table 1.

Energy intake (EI)

During the race total energy intake was 51,246 kcal (215 MJ) with an average of 8,541 ± 4,153 kcal per day, consisting of 1,612 ± 795 g carbohydrates, 136 ± 72 g fat and 217 ± 102 g protein. Of total calories, 75.4 % were from carbohydrates, 12.7 % from fat and 11.5 % from protein (Table 2).

Table 1. Relationship between heart rate and the rate of energy expenditure (EE) during incremental exercise (VO_2max test).

Exercise bout (Watt)	**Heart rate** ($b \cdot min^{-1}$)	**EE** ($kcal \cdot min^{-1}$)
Rest	72	2.53
100	115	7.78
130	122	9.21
160	135	10.33
190	142	11.94
220	155	13.59
250	165	14.92
280	174	16.58
310	183	17.59
340	194	18.93
370	202	20.52
400	206	21.45

Energy expenditure (EE) during the race

Collecting data from the POLAR® S710, during the whole race suggested the athlete expended a total energy of 80,800 kcal (338 MJ) with a daily energy expenditure of 13,467 ± 4,850 kcal (Table 3). In contrast calculating EE from the individual relationship between heart rate and VO_2 (Table 1), the athlete's EE was 58,357 kcal (244 MJ) for the whole race.

Energy deficit

Energy deficit was calculated as the difference between EI and EE. Energy deficit (ED) estimated from continuous heart rate monitoring was 29,554 kcal (124 MJ), and ED calculated from the individual relationship between heart rate and VO_2 was 7,111 kcal (30 MJ).

Body mass and body composition

The athlete lost two kg in body mass (Figure 1). Fat mass was reduced by 790 g (13.8 %) and fat free mass (FFM) decreased from 61.5 kg to 60.29 kg (1.9 %). Percentage body fat showed a reduction from8.49 % to 7.53 % (Figure 1). Circumference of the upper extremities remained stable, whereas skinfold thickness in the lower extremities increased (Table 4) and circumference decreased (Figure 2).

Table 2. Daily energy intake derived from carbohydrate (CHO), fat and protein during the race.

Day	**CHO** (g)	**Fat** (g)	**Protein** (g)	**CHO** (kcal)	**Fat** (kcal)	**Protein** (kcal)	**Total EI** (kcal)
1	1,629	164	294	6,516 (71.1 %)	1,476 (16.1 %)	1,176 (12.8 %)	9,168
2	1,357	104	197	5,428 (75.9 %)	936 (13.1 %)	788 (11.0 %)	7,152
3	1,413	89	248	5,652 (75.9 %)	801 (10.8 %)	992 (13.3 %)	7,445
4	2,039	168	200	8,156 (77.9 %)	1,512 (14.5 %)	800 (7.6 %)	10,468
5	2,815	249	325	11,260 (76.1 %)	2,241 (15.1 %)	1,300 (8.8 %)	14,801
6	417	44	37	1,668 (75.3 %)	396 (18.0 %)	148 (6.7 %)	2,212
Average	1,612	136	217	6,447 (75.4 %)	1,227 (14.6 %)	867 (10.0 %)	8,541
Total	9,670	818	1,301	72,279	7,362	5,204	51,246

Table 3. Daily performance and percentage energy expenditure (EE) derived from carbohydrate (CHO) and fat during the race.

Day	Distance* (km)	Altitude** (m)	CHO (%)	Fat (%)	EE (kcal)	EI-EE (kcal)
1	591	14,448	73.5	26.5	17,430	- 8,262
2	1,084	25,630	71.2	28.8	16,893	- 9,741
3	1,495	35,270	62.5	37.5	14,278	- 6,833
4	1,846	44,739	61.1	38.9	14,106	- 3,638
5	2,218	54,276	60.7	39.3	14,048	753
6	2,272	55,455	60	40	4,045	- 1,833
Average	-	-	64.8	35.2	13,467	- 4,926
Total	2,272	55,455	-	-	80,800	- 29,554

EI = energy intake. *Cumulative distance, ** Cumulative altititude.

Table 4. Skinfold thickness (mm).

Day	Calf	Knee
1	5.4	4.8
2	-	-
3	4.0	4.7
4	4.0	4.2
5	-	-
6	6.8	5.2

Fluid turnover
A total water intake, in liquid form, of 60.1 L with an average of 10 L per day was measured. Excretion of urine varied from 1.43 to 2.85 litres per day (except day 6) (Table 5).

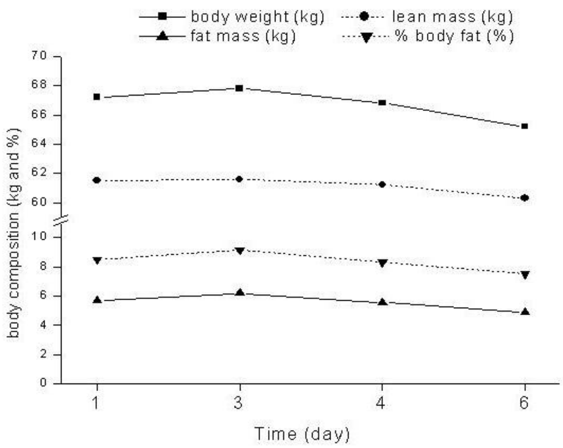

Figure 1. Change of body mass (kg) and body composition (%) over six days.

Blood parameters
Haematology and protein values remained stable, creatine kinase (CK) increased while testosterone decreased (Table 6).

DISCUSSION

The main finding of this case study is that a discrepancy existed between the two methods of determining exercise EE. Measuring EE via continuous heart rate monitoring during exercise has been discussed (Achten and Jeukendrup, 2003; Crouter et al., 2004) and we therefore used additionally the method of the athlete's individual relationship between heart rate and VO_2 to assess EE. Using this individual relationship, we calculated an EE of 58,357 kcal (244 MJ) for the whole race compared with 80,800 kcal (338 MJ) using the POLAR® S710.

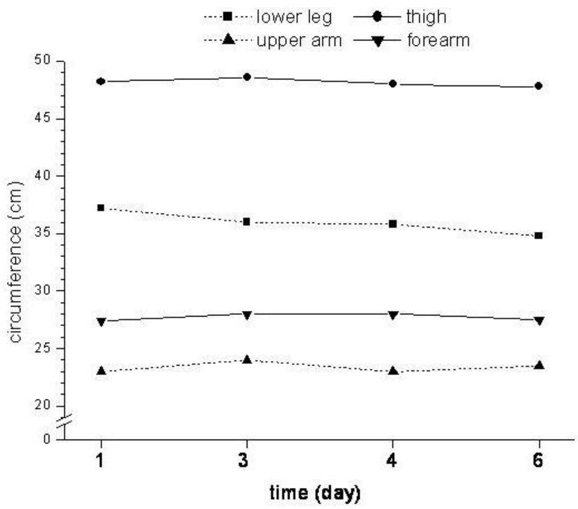

Figure 2. Change in circumference of upper and lower limbs over six days.

The cyclist lost 2.0 kg body mass, corresponding to 11,950 kcal (50 MJ). Fat mass was reduced by 790 g (7,110 kcal) and fat free mass by 1.21 kg (4,840 kcal). Energy deficit estimated using continuous heart rate monitoring was 29,554 kcal

(124 MJ), and using the individual relationship between heart rate and VO_2 7,111 kcal (30 MJ). Neither method matches the 50 MJ EE calculated from the decrease in body mass. With continuous heart rate monitoring there was a discrepancy of 17,604 kcal (74 MJ) and with the individual relationship between heart rate and VO_2 a discrepancy of 4,840 kcal (20 MJ).

These differences cannot properly be explained. An energy deficit of 5,000 to 10,000 kcal corresponds to about 1 kg of fat or 2 to 4 kg of muscle. Our data indicates that the individual relationship between heart rate and VO_2 may provide a closer estimate of exercise EE compared with corresponding data derived from the POLAR® S710.

One reason for the difference in methodology could be that EE was too highly estimated using the POLAR® S710, or body mass, and especially skinfold thickness, were influenced by fluid overload or oedemas.

Determination of EE using heart rate measurements (POLAR® S710)

It has been suggested that heart rate recording with a portable heart rate monitor during field conditions is as accurate as measuring heart rate with an ECG (Kingsley et al., 2005). Also heart rate recording in the field is feasible, reasonably priced and accurate due to the new technology of portable heart rate monitors (Hiilloskorpi et al., 2003).

Compared with indirect calorimetry or the doubly-labelled water technique, the heart rate method shows no difference, even when differences between subjects and within subjects are reported (Li et al., 1993).

Nevertheless measuring EE using continuous heart rate monitoring has limitations. During field conditions, heart rate is influenced by emotion, high temperature, high humidity, dehydration and illness (Davidson et al., 1997). The determination of EE by HR is useful as a group mean, but interpretation of the individual EE requires caution because of great deviations from the reference values (Kashiwazaki, 1999; Livingstone et al., 1990). Thus the methodology employing continuous heart rate monitoring may over estimate EE. Indeed EE measured using heart rate has been reported to be 6 % higher compared with EE derived using the technique of doubly-labelled water (Davidson et al., 1997). Similarly during measurements in the field, continuous heart rate monitoring to estimate EE shows a difference compared with the technique of using doubly-labelled water (Kashiwazaki, 1999).

Table 5. Fluid intake and urine excretion during the race

Day	Fluid intake (L)	Urine (L)
1	14.4	1.85
2	9.9	2.85
3	10.4	1.75
4	10.3	1.43
5	12.3	1.75
6	2.8	0
Average	10	1.60
Total	60.1	9.63

In addition to the use of portable heart rate monitors, the relationship between heart rate and VO_2 (which reflects energy expenditure as oxygen uptake) provides another method for predicting EE. It is possible to estimate EE from heart rate during submaximal exercise with a great deal of accuracy, after adjusting for age, gender, body mass and fitness (Keytel et al., 2005). The relationship between heart rate and oxygen uptake seems to be linear during dynamic exercise up to about 85 % of the individual maximum heart rate (HR max) (Li et al., 1993). During the race our athlete had an

Table 6. Blood parameters before, immediately after and 5 weeks after the race.

	Before	Immediately after	5 weeks after
Leukocytes ($x10^9 \cdot L^{-1}$)	5.40	5.40	5.80
Erythrocytes ($x10^9 \cdot L^{-1}$)	4.80	4.65	4.86
Haematocrit (%)	0.45	0.44	0.45
Haemoglobin ($g \cdot L^{-1}$)	153	145	151
Testosterone ($ng \cdot dL^{-1}$)	327	185*	644
Protein ($g \cdot dL^{-1}$)	7.2	7.1	7.2
CK ($U \cdot L^{-1}$)	217	1 636	138
Albumin ($mg \cdot dL^{-1}$)	4 670	3 930	value missing

average heart rate of 130 to 140 beats per minute b min^{-1} (63 to 67 % HR max) in the first half of the race, then it dropped to 110 to 120 b min^{-1} (53 to 58 % HR max) in the second half.

Loss of muscle mass and muscle protein during extreme endurance exercise

We assume that the energy deficit was covered by degradation of subcutaneous adipose tissue and muscle mass of the exercising limbs. Skinfold thickness in the lower limbs increased (Table 4) and circumferences decreased (Figure 2). We presume that muscle mass decreased, and therefore hypoproteinemic oedemas of the lower limbs occurred. Oedemas may explain the increase of skinfold thickness with increasing duration of the race. It is fundamental that during long lasting physical activity, besides the energy-rich substrates such as carbohydrates and fat, protein is diminished. During running, a reduction of the concentration of alanine and prolin shows up in the serum, whilst the concentration of glucose and free fatty acids rises (Huq et al., 1993). During very long endurance exercise it has been shown that a continuous degradation of muscle protein (Raschka et al., 1991; Volk and Neumann, 2000) results in the reduction of the concentration of albumin and total protein (Robertshaw and Swaminathan, 1993). During an extreme running race in Alaska, the athletes ingested mainly carbohydrates. They also lost body mass, and with associated ketonuria and proteinuria, it was concluded that proteins were metabolised to support EE (Case et al., 1995).

Hypoproteinemia and oedemas

We presume that an increase of body mass during extreme endurance exercise is due to hypoproteinemic oedemas. In extreme endurance exercise the circulating protein in the blood decreases and the plasma volume increases. Lehmann and co-workers (1995) showed in a Double Ironman Triathlon an increase in plasma volume of about 15.4 %.

An increase of several kilograms body mass due to oedemas may be apparent before oedemas become clinically obvious. Possible etiologies for oedemas are a reduced blood volume, leakage of capillaries, kidney factors, reduced heart minute volume and a reduced oncotic pressure. The oncotic pressure of the plasma can be reduced by factors which lead to severe hypalbuminemia: for example an increased salt supply, lack of nutrition, liver damage, loss of protein over the urinary or gastrointestinal system or a severe catabolic situation (Golden, 1982).

CONCLUSIONS

During an ultra distance cycle race, the energy deficit does not correspond to the loss of subcutaneous adipose tissue and muscle mass (50 MJ as units of energy). With continuous heart rate monitoring the total ED was (17,604 kcal) (74 MJ) and using the individual relationship between heart rate and VO_2 (7,111 kcal) (30 MJ). This difference cannot properly be explained - although body mass and skinfold thickness may be overestimated due to hypoproteinemic oedemas.

Our data suggests estimating EE using the individual relationship between heart rate and oxygen uptake may be a more accurate method than the continuous monitoring heart rate per se, based on a generalised algorithm.

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REFERENCES

Achten, J, and Jeukendrup, A.E. (2003) Heart rate monitoring: applications and limitations. *Sports Medicine* **33**, 517-538.

Achten, J., Venables, M.C. and Jeukendrup, A.E. (2003) Fat oxidation rates are higher during running compared with cycling over a wide range of intensities. *Metabolism* **52**, 747-752.

Atwater, W.O. (1909) Coefficients of digestibility and availability of the nutrients of food. *Proceedings of the American Physiology Society* **30**, 14-19.

Case, S., Evans, D., Tibbets, G., Case, S. and Miller, D. (1995) Dietary intake of participants in the Iditasport Human Powered Ultra-marathon. *Alaska Medicine* **37**, 20–24.

Colombani, P.C., Mannhart, C., Wenk, C. and Frey, W.O. (2002) Nutritional intake during a 244 km multisport ultraendurance race. *Pakistan Journal of Nutrition* **1**, 124-126.

Coyle, E.F., W.H. Martin, A.A. Ehsani, J.M. Hagberg, S.A. Bloomfield, D.R. Sinacore, et al. (1983) Blood lactate threshold in some well-trained ischemic heart disease patients. *Journal of Applied Physiology* **54**, 628-634.

Crouter, S.E., Albright, C. and Bassett, D.R. Jr. (2004) Accuracy of polar S410 heart rate monitor to estimate energy cost of exercise. *Medicine and Science in Sports and Exercise* **36**, 1433-1439.

Der kleine "Souci-Fachmann-Kraut". Lebensmitteltabelle für die Praxis (1991). Deutsche Forschungsanstalt für Lebensmittelchemie, Garching bei München, 2. Auflage, Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart. (In German).

Davidson, L., McNeill, G., Haggarty, P., Smith, J.S. and Franklin, M.F. (1997) Free-living energy expenditure of adult men assessed by continuous heart-rate monitoring and doubly-labelled water. *British Journal of Nutrition* **78**, 695-708.

Dressendorfer, R.H. and Wade, C.E. (1991) Effects of a 15-d race on plasma steroid levels and leg muscle fitness in runners. *Medicine and Sciene in Sports and Exercise* **23**,954-958.

Frayn, K.N. (1983) Calculation of substrate oxidation rates in vivo from gaseous exchange. *Journal of Applied Physiology* **55**, 628-634.

Golden, M.H.N. (1982) Protein deficiency, energy deficiency, and the oedema of malnutrition. *Lancet* **1**, 1261

Hiilloskorpi, H.K., Pasanen, M.E., Folgelholm, M.G., Laukkanen, R.M. and Manttari, A.T. (2003) Use of heart rate to predict energy expenditure from low to high activity levels. *International Journal of Sports Medicine* **24**, 332-336.

Huq, F., Thompson, M. and Ruell, P. (1993) Changes in serum amino acid concentrations during prolonged endurance running. *Japanese Journal of Physiology* **43**, 797-807.

Jackson, A.S. and Pollock, M.L. (1985) Practical assessment of body composition. *Physician and Sports Medicine* **13**, 76-90.

Kashiwazaki, H. (1999) Heart rate monitoring as a field method for estimating energy expenditure as evaluated by the doubly labelled water method. *Journal of Nutritional Science and Vitaminology* **45**, 79-94.

Keytel, L.R., Goedecke J.H., Noakes T.D., Hiiloskorpi H., Laukkanen R., van der Merwe L., and Lambert E.V. (2005) Prediction of energy expenditure from heart rate monitoring during submaximal exercise. *Journal of Sports Science* **23**, 289-297.

Kingsley, M, Lewis, M.J. and Marson R.E. (2005) Comparison of Polar 810s and an ambulatory ECG system for RR interval measurement during progressive exercise. *International Journal of Sports Medicine* **26**, 39-44.

Knechtle, B., Enggist, A. and Jehle, T. (2005) Energy turnover at the Race Across America (RAAM) – a Case Report. *International Journal of Sports Medicine* **26,** 499-503.

Knechtle, B. and Marchand, Y. (2003) Schwankungen des Körpergewichts und der hautfaltendicke bei einem athleten während eines extremausdauerwett-kampfes. *Schweizerische Zeitschrift für Sportmedizin* **51**, 174-178. (In German).

Knechtle, B., Knechtle, P., Müller, G. and Zwyssig, D. (2003a) Energieumsatz an einem 24 stunden radrennen: Verhalten von körpergewicht und subkutanfett. *Österreichisches Journal für Sportmedizin* **33**, 11-18. (In German).

Knechtle, B., Zapf, J., Zwyssig, D., Lippuner, K. and Hoppeler, H. (2003b) Energieumsatz und muskelstruktur bei langzeitbelastung: eine fallstudie. *Schweizerische Zeitschrift für Sportmedizin* **51**, 180-187. (In German).

Knechtle, B., Bisig, A., Schläpfer, F. and Zwyssig, D. (2003c) Energiebilanz bei langzeitbelastung: eine fallstudie *Praxis* **92**, 859-864. (In German).

Knechtle, B., Müller, G., Willmann, F., Kotteck, K., Eser, P. and Knecht, H. (2004) Fat oxidation in men and women endurance athletes in running and cycling. *International Journal of Sports Medicine* **25**, 38-44.

Knechtle, B. and Bircher, S. (2005) Veränderung der körperzusammensetzung bei einem. Ultralauf *Praxis* **94**, 371-377. (In German).

Knechtle, B., Enggist, A., and Jehle, T. (2005) Energy turnover at the Race Across America (RAAM) – a case report. *International Journal of Sports Medicine* **26**, 499-503.

Krogh, A. and Lindhard, J. (1920) Relative value of fat and carbohydrate as a source of muscular energy. *Biochemical Journal* **14**, 290-298.

Lehmann, M., Huonker, M., Dimeo, F., Heinz, N., Gastmann, U., Treis, N., Steinacker, J.M., Keul, J., Kajewski, R. and Haussinger, D. (1995) Serum amino acid concentrations in nine athletes before and after the 1993 Colmar ultra triathlon. *International Journal of Sports Medicine* **16**, 155-159.

Li, R., Deurenberg, P. and Hautvast, J.G.A.J. (1993) A critical evaluation of heart rate monitoring to assess energy expenditure in individuals. *American Journal of Clinical Nutrition* **58**, 602-607.

Livingstone, M.B., Prentice A.M., Coward W.A., Ceesay S.M., Strain J.J., McKenna P.G., Nevin G.B., Barker M.E. and Hickey R.J.(1990) Simultaneous measurement of free-living energy expenditure by the doubly labelled water method and heart-rate monitoring. *American Journal of Clinical Nutrition* **52**, 59-65.

Nagel, D., Seiler, D., Franz, H., Leitzmann, C. and Jung, K. (1989) Effects of an ultra-long-distance (1000 km) race on lipid metabolism. *European Journal of Applied Physiology* **59**, 16-20.

Raschka, C., Plath, M., Cerull, R., Bernhard, W., Jung, K. and Leithmann, C. (1991) Das Körpermuskel-kompartiment und seine beziehungen zur nahrungsaufname und blutchemie unter einer extremen ausdauerbelastung. *Zeitschrift für Ernährungswissenschaften* **30,** 276-288. (In German).

Raschka, C. and Plath, M. (1992) Das Körperfett-kompartiment und seine beziehungen zur nahrungsaufnahme und klinisch-chemischen parametern während einer extremen ausdauerbelastung. *Schweizerische Zeitschrift für Sportmedizin* **40**, 13-25. (In German).

Reynolds, R.D., Lickteig, J.A., Deuster, P.A., Howard, M.P., Conway, J.M., Pietersma, A., De Stoppelaar, J. and Deurenberg, P. (1999) Energy metabolism increases and regional body fat decreases while regional muscle mass is spared in humans climbing Mt. Everest. *Journal of Nutrition* **129**, 1307-1314.

Robertshaw, M. and R. Swaminathan, R. (1993) Biochemical changes after a 100 km hill walk. *Journal of Medicine* **24**, 311-324.

Romijn, J.A., Coyle, E.F., Sidossis, L.S., Gastaldelli, A., Horowitz, J.F., Endert, E. and Wolfe, R.R. (1993) Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. *American Journal of Physiology* **265**, E380-E391.

Volk, O. and Neumann, G. (2000) Verhalten ausgewählter metaboler und hormoneller parameter während eines Dreifachlangtriathlons. *Österreichisches Journal der Sportmedizin* **4**,18-23. (In German).

KEY POINTS

- During an extreme endurance cycling race, energy expenditure can not be covered by energy intake and an energy deficit results.
- The energy deficit seems to be covered by degradation of subcutaneous adipose tissue and muscle mass.
- Determination of energy expenditure during extreme endurance may be properly determined with the individual correlation of heart rate - VO_2 instead of continuous heart rate monitoring.

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