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CHANGES IN BODY COMPOSITION INDUCED BY DIET AND EXERCISE

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Abstract. Nutritional status is commonly described in terms of the body mass index (*BMI*), defined as body mass (kg) divided by height (m) squared. Adults with $BMI \geq 30$ kg/m^2 are classified as obese by the World Health Organization. *BMI*, however, is a poor indicator of fatness because it does not contain information on the nature and distribution of body mass. Therefore, a more refined analysis of body composition is needed for assessing the benefits of changes in diet and lifestyle. The simplest, two-compartment model of body composition distinguishes fat and fat-free body. By measuring the mass of these components, one can describe fatness in terms of per cent body fat (%*BF*), as well as the fat mass index (*FMI*), defined as fat mass (kg) divided by height (m) squared. These quantities can be measured, for example, by densitometry. In this work, we report changes in body composition as a result of a 4 week program of diet and exercise, specifically designed to gain muscle mass while lowering %*BF* and *FMI*. The diet aimed at decreasing specific macronutrients to ensure a slight, steady calorie deficit. It was high in protein, supplying most of the energy expenditure of the body, as well as nutrients needed to stimulate muscle growth. The exercise program, based on resistance training combined with conditioning training, was meant to stimulate muscle growth. The resistance training, involving heavy muscle contractions, was more likely to use up glucose. The conditioning training (done in the morning, on an empty stomach, with a low, but steady blood sugar) increased lipolysis and boosted the metabolic rate, resulting in a higher calorie consumption throughout the day. We performed weekly measurements, after overnight fasting, by air displacement plethysmography using the BOD POD Body Composition Tracking System, ultrasound anthropometry (US), and bioelectrical impedance analysis (BIA). The subject did weekly blood tests (blood cells count, liver enzymes) to ensure that the training and diet programs are safe. Body mass management requires a careful balance between diet and exercise, and body monitoring techniques are essential in assuring this balance.

Key words: air displacement plethysmography, bioelectrical impedance analysis, ultrasound.

INTRODUCTION

As the worldwide obesity rate is continuously rising, there is an increasing need for effective and risk-free methods to maintain a healthy body weight [13].

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Energetically, the human body can be viewed as an open system that uses food as primary energy source for vital processes. In a healthy body, the energy intake and consumption are in balance. However, the uses of inappropriate food sources and/or prolonged exposure to a sedentary lifestyle or stress can alter this balance. The energy excess is stored as fat and can be accompanied by a decrease in the muscle mass. In such cases, the restoration of a healthy and sustainable balance can be difficult. Modern techniques for assessing human body composition are useful in monitoring such efforts [9].

The objective of this work was to devise and evaluate a methodology for decreasing body mass by lowering the amount of body fat while maintaining or even increasing muscle mass. One healthy and active individual participated voluntarily in this study, following a rigorous nutritional and training plan. Having an active lifestyle with energy intensive needs, the nutrition plan was designed to provide the necessary calories, the macro- and micronutrients needed for the training and recovery periods, in accordance with the established objective [7]. Therefore, the nutrition plan was designed to account for the dynamic balance of the body during the study.

Proteins in the human body are polymers composed of 21 types of amino acids, 10 of which are considered essential because they cannot be synthesized by the body [7, Ch. 5]. Hence, they should be supplied by exogenous intake. In order to maintain, respectively to increase muscle mass, the human body needs all amino acids, and especially the branched-chain ones: leucine (LEU), isoleucine (ILE) and valine (VAL). The branched-chain amino acids play a key role in the protein synthesis inside cells, as they make up a third of the skeletal muscle mass. Among the above mentioned three, leucine (LEU) is the most important one, since it can reduce the degradation of muscle mass (protein catabolism) in a similar way to insulin.

Carbohydrates represent the primary energy source for the body, containing 4 kcal energy per gram [7, Ch. 4]. The amount and rate of insulin secretion is induced by how fast blood glucose rises, but also by the amount and type of ingested carbohydrates. Being a storage hormone, apart from regulating glucose uptake by cells, insulin contributes to feeding and storing triglycerides in fat, blocking lipid oxidation and boosting cholesterol production. Hence, when insulin levels are high, there is little chance to burn body fat in order to cover the energy needs of the body.

When the liver and muscle storage capacities are exceeded, the remaining carbohydrates are metabolized into fatty acids. The liver, under the influence of insulin, is highly effective in the metabolism of glucose into fatty acids. These are then delivered to the adipocytes, being stored as triglycerides in the adipose tissue.

Polysaccharides are sources of complex carbohydrates, consisting of long glucose molecules which have a significant amount of fiber. Their absorption in the blood is slow, since it takes a long time for them to degrade into monosaccharides.

Therefore, their consumption leads to a more stable glycemic level and a lower insulin secretion rate. Instead, simple carbohydrates, having only monosaccharide or disaccharide structure, are absorbed into the blood fast. They lead to a sudden rise in the blood glucose level and to an accelerated insulin secretion rate.

Food fibers are a category of carbohydrates that are contained in foods of plant origin. These types of carbohydrates cannot be digested. However, they greatly help digestion by reducing blood cholesterol and, very importantly, controlling the release of glucose in the blood. Food fibers are divided into two categories: soluble and insoluble fibers. The soluble ones, such as cellulose or lignin, have a high absorption capacity and help to build the fecal bowel and to regulate digestion. The insoluble fibers, like pectin and hemicellulose, slow down the release of glucose in the bloodstream, maintaining stable blood sugar and normal insulin levels.

Lipids are the most effective source of energy, having 9 kcal per gram. They represent a major component of the cell membrane and an important deposit for liposoluble vitamins such as vitamins A, K, D, and E. After lipids degrade into fatty acids and monoacylglycerides by the digestive system, short- and medium-chain fatty acids will be transported by the blood, along with the rest of the nutrients, directly into the liver [7, Ch. 6]. These are much easier to oxidize and become available for energy generation than long-chain fatty acids. On the other hand, the long-chain fatty acids, which also diffuse through the epithelial cells of the small intestine, are metabolized into triglycerides, being transported in the blood in the form of chylomicrons or lipoproteins. As they arrive into muscles, adipose tissue, or any other tissue, the lipoprotein lipase enzyme hydrolyses triglycerides in order to release energy, to create bases in hormone production, or simply to be stored in fat cells. When the insulin level is very high, the body enters the storage state, meaning that the fatty acids in the bloodstream will mainly be transported to the fat cells for storage. Therefore, the consumption of simple carbohydrates along with lipids is not indicated.

Vitamins are divided into two categories: liposoluble and water-soluble. Vitamins A, D, E, and K, being liposoluble, are absorbed into the organism only in the presence of lipids and are stored in the adipose tissue [7, Ch. 8]. The water-soluble ones consist of the B-complex and vitamin C. For the latter, their penetration into the fat cells is more difficult, most of them being eliminated. Hence, constant intake of vitamins from food sources is very important.

Hydration before, during, and after training is of critical importance. Training regimes, such as those used in this study, induce carbohydrate consumption, increase body temperature, reduce volition and dehydrate the body, eliminating plenty of water and salts by sweating [7, Ch. 7]. The amount of water and salts in the body must be constantly balanced by consuming various types of liquids. Plain water, however, is not the optimal source of hydration in this case. The addition of electrolytes and a source of simple carbohydrates, such as pure glucose (from both food intake and synthesized sources), will significantly increase the subject's performance. Sources of electrolytes are minerals, whose aqueous solutions contain calcium, chlorine, magnesium, phosphorus, potassium and sodium ions. Ingested electrolytes reach body fluids, contribute to buffer solutions responsible for maintaining blood pH, and influence important functions such as muscle contraction, or water distribution in the body.

In this study, we monitored changes in body composition based on the two compartments model of the human body. It views the body as being made of fat and fat-free components. Based on the experimental observation that, in adults, fat density is about 0.9 g/cm^3, whereas fat-free tissues have an average density of 1.1 g/cm^3 [10], with negligible variation with sex, age or ethnicity, body fat percentage can be computed using the Siri equation [10]:

$$\%BF = \left(\frac{4.95}{D} - 4.5\right) \times 100\% \tag{1}$$

where D denotes body density expressed in g/cm^3.

To monitor the efficacy of the sports and nutrition program proposed in this work, we performed weekly measurements of $\%BF$, after overnight fasting, by air displacement plethysmography [1, 5, 6], ultrasound (US) anthropometry [12], and bioelectrical impedance analysis (BIA) [3, 4].

MATERIALS AND METHODS

MAINTAINING/INCREASING THE MUSCLE MASS

This study was performed on the first author (CS): a voluntary male subject, aged 25 years. He is a nutritionist and certified personal trainer, with extensive experience in sports and exercise. He designed the training program and contributed to the nutritional plan. Throughout the study, he conducted a diary, recording the details of training and diet, and the data were analyzed by all authors.

During the post-training recovery period, muscle protein synthesis increases if it is accompanied by a consumption of an adequate amount of amino acids. Intake of fast-absorbing proteins with high bioavailability, such as whey concentrates, induce a rapid increase of amino acid concentration in the blood serum, boosting protein synthesis by up to 68%, while having minimal effect on protein degradation. Instead, the slow-absorbing protein sources such as egg-whites, cow cheese and casein concentrates, inhibit the protein degradation by up to 30% over a seven-hour period after ingestion, while having minimal effect on protein synthesis. Table 1 summarizes the main sources of fast- and slow-absorbing proteins and their bioavailability [7].

Table 1

Protein sources and their bioavailability

Protein source	Bioavailability (%)
Whey concentrates	104
Whole eggs	100
Cow cheese	90
Beef	80
Casein concentrate	77
Soya	74

REDUCING BODY FAT MASS

The physical effort required to decrease the body fat mass is sustained by the intake of carbohydrates and dietary fiber.

Low carbohydrate consumption in the morning, before the cardiovascular conditioning training, leads to a decrease of the insulin level and a rise of the glucagon level. This stimulates the fat cells to release their lipidic load in order to be used for energy creation, through the process of lipolysis [8]. Further, the low insulin level will inactivate the ability of fat cells to absorb additional lipids, which will result in a decrease of their size, having a major effect on the overall body composition.

In order to achieve the above mentioned goal, the exercise program was designed with the following characteristics:

- sustained caloric deficit, applied gradually, with additional 150 kcal weekly decrease, cumulative for a period of five weeks (the daily average energy input is estimated to be about 2600 kcal/day in the first week);
- daily training sessions consisting of high intensity interval training (HIIT) for 15–20 minutes and resistance training (RT) for about 35 minutes.

In the proposed nutritional plan, the 150 kcal energy deficit was subtracted from carbohydrate intake, while the protein and lipid intakes remained unchanged. Furthermore, the daily ratios of macronutrients were continuously adjusted, depending on the day-to-day type of training.

In the days of RT, the carbohydrate intake exceeded the fat intake, since this type of training requires a higher glucose consumption. Instead, in the days of HIIT training, the consumption of lipids outweighed that of carbohydrates, since this type of training creates less stress to the muscles and lasts less. Nevertheless, being performed before breakfast, at relatively low blood glucose level, such a training is likely to trigger lipolysis, a process that is non-uniformly distributed throughout the body [8].

By applying an energy deficit in conjunction with a training program, we hypothesized that the body fat mass will decrease, while the muscle mass will not change, or it might even slightly increase.

In the plan of the five daily meals, the total energy requirements are detailed, as well as the proportion of each macronutrient, corresponding to that day's training regime. As an example, Tables 2 and 3 show the meal plans of week 4, for a resistance training and high-intensity interval training day, respectively.

The implementation of this plan was carried out by calculating, for each meal separately, the type and quantities of foods that provide the necessary nutrients in the proposed plan.

Table 2

Example of meal program characteristics for a day with RT in week 4

Meal	Per cent energy content (%)	Energy content (kcal)	Types of macronutrients	Amounts of macronutrients per day	
MD	25	537.5		grams	%
P	25	537.5	proteins	195	36.28
C	20	430	carbohydrates	180	33.49
G1	15	322.5	lipids	72.2	30.23
G2	15	322.5			
TOTAL	100	2150			

Abbreviations: MD – breakfast, G1 – first snack, P – lunch, G2 – second snack, C – dinner.

The RT and HIIT workouts were held separately, on different days, to avoid harm to the body.

Table 3

Example of meal program characteristics for a day with HIIT in week 4 (abbreviations as in Table 2)

Meal	Per cent energy content (%)	Energy content (kcal)	Types of macronutrients	Amounts of macronutrients per day	
MD	25	537.5		grams	%
P	25	537.5	proteins	195	36.28
C	20	430	carbohydrates	115	21.4
G1	15	322.5	lipids	101.1	42.32
G2	15	322.5			
TOTAL	100	2150			

Cardiovascular conditioning HIIT training was performed for 15 minutes on an empty stomach, divided into two five-minute exercises, on any type of cardio fitness machine. The training was done at high intensity with alternating intervals of active pause and accelerating of 30 seconds each, resulting in the transition from aerobic mode to anaerobic regime, and vice versa. Between the two rounds, 5 minutes of training for the frontal and oblique abdominal muscles was performed. Hence, HIIT targets the overall fat reserve, whereas the abdominal exercise nested between the cardio trainings aims to reduce the fat deposits of the abdomen.

The aerobic effort is sustained by the oxygen transported directly from the lungs to the muscles, without affecting the oxygen reserves of the body. This type of effort is prolonged and produces a low amount of lactic acid. During this effort, the cardiovascular system functions within normal limits, with almost insensible changes in heart rate.

The anaerobic effort is achieved at a higher intensity and for a relatively short time, leading to a consumption of the oxygen reserves of the body. As a result, there is a higher production of lactic acid, while the heart rate increases significantly; it returns to normal level during the recovery period. This type of effort is used in the accelerating periods of the training, resulting in a higher content of inhaled oxygen, until $VO_{2\max}$ is reached. After attaining the $VO_{2\max}$ level, induced by the anaerobic threshold, the basal metabolic rate (BMR) is increased during the post-workout period. This will assure a sustained caloric deficit throughout the day, due to the increased recovery period.

The cardiovascular conditioning training was done three times a week, with the intensity being kept the same during each session, as shown in Table 4.

In order to be able to complete all the proposed exercises, the resistance strength training usually takes place after 18:00, when the glycogen reserves of the body are filled. Three training sessions were held each week, targeting all muscle groups, as detailed in Table 5.

Table 4

The cardiovascular conditioning workout plan used in this study

running	30 s 2/4 (aerobic) × 5 sets	30 s 4/4 (anaerobic) × 5 sets
crunches	3 sets	20 repetitions
running	30 s 2/4 (aerobic) × 5 sets	30 s 4/4 (anaerobic) × 5 sets

Three sets consisting of 12, 10 and 8 repetitions were performed for each exercise. The effort was anaerobic, and rest periods of 45–60 seconds were held between each set. The most important aspect of this training was to stimulate protein synthesis, leading to an increase in strength and muscle mass. The intensity of the training remained constant throughout the program, the only change being the carbohydrates deficit within the nutrition plan.

Table 5

Daily division of strength training exercises in resistance mode

Day	Training sessions	Training machines	Sets	Repetitions	Rest (s)
Tuesday	Upper body	4	3	12, 10, 8	60
Thursday	Lower body	4	3	12, 10, 8	60
Saturday	Arm muscles	4	3	12, 10, 8	60

The weekly schedule of meals and training is shown in Table 6. It consists in 6 training days (3 of resistive strength training and 3 of conditioning training) and a day of stretching (Sunday).

Table 6

Weekly timetable with nutrition and training periods (abbreviations as in Table 2)

Monday	Cardio	MD		G1	P	G2		C
Tuesday		MD		G1	P	G2	Strength	C
Wednesday	Cardio	MD		G1	P	G2		C
Thursday		MD		G1	P	G2	Strength	C
Friday	Cardio	MD		G1	P	G2		C
Saturday		MD	Strength	G1	P	G2		C
Sunday	Stretching	MD		G1	P	G2		C

In order to create an oxidative environment for the fatty acids, no food was consumed for at least half an hour after finishing the cardiovascular conditioning session.

On the other hand, after the more demanding strength training session, a rich carbohydrate intake was ensured during the pre-training meals. Therefore, lunch (P) and second snack (G2) contained a minimum of 30 grams of fast-absorbing proteins (*e.g.* whey concentrate) together with 35–40 grams of simple carbohydrates. These nutrients raised the blood sugar, thus stimulating the secretion of insulin, which supported an anabolic environment during exercise, avoiding protein degradation. Immediately after the training session, fast-absorbing protein is needed, as the body's ability to stimulate protein synthesis is accelerated during this period. Approximately 25 to 30 grams of fast-absorbing protein ingested along with a simple carbohydrate source will suddenly increase insulin levels and increase the protein synthesis by up to 400%.

During strength training, isotonic drinks and glucose-rich beverages were consumed. It is known that the absorption and release of these nutrients and minerals is rapid, providing optimal hydration during the training.

During the cardiovascular conditioning workouts carbohydrate-rich drinks were not consumed, since this training was preformed before the first meal, and the goal was to keep the body blood sugar levels low. Instead, only electrolyte-rich beverages were consumed.

Blood testing was performed weekly in order to observe the status of body parameters under sustained effort and hyperproteic nutrition plan.

MONITORING BODY COMPOSITION

For air displacement plethysmography, we used a BOD POD Gold Standard Body Composition Tracking System (Cosmed, USA), a reference technique for body composition analysis. This device assesses the density of the whole body by measuring the volume of dislodged air by the body inside a hermetically closed chamber [5, 6].

The technical error of a BOD POD measurement is of about 1.7% body fat [1]. Before a BOD POD test, the subject was asked to refrain from eating and drinking for at least 2 hours, and to urinate at least 30 minutes before the test was started.

Body composition was also assessed using the BodyMetrix device (Intelametrix, USA), an A-mode ultrasound instrument that records the position of tissue interfaces beneath the skin. Recording subcutaneous tissue thickness in representative points of the human body allows to estimate body density and percent body fat.

Three models of body density estimates were used as implemented in the BodyView software of the BodyMetrix instrument: the Sloan formula [11], the 3 points Jackson-Pollok formula (J-P 3), and the 7 points Jackson-Pollok (J-P 7) formula [2].

For BIA, we used a BioScan 920-II instrument (Maltron, UK) whose function is based on the measurement of the electrical impedance of tissues when crossed by alternating currents [3, 4].

RESULTS

In this study, the monitored parameters were chosen according to the proposed objective. We measured body mass and body fat mass, and we performed medical laboratory tests needed to assess the general health of the subject. All measurements were carried out weekly.

MEDICAL LABORATORY RESULTS

In the first set of blood tests (week 1), elevated CK value (464 U/L) was observed, indicating damage to the sheath muscle fiber resulting from sustained physical effort. Also, the CK-MB enzyme has a small increase (29 U/L), but which is not a pathological problem because there are no other changes to the investigated parameters. It is presumed that this increase may also be related to the sustained training.

In the fourth set of blood tests (week 4), a CK increase (up to 993 U/L) was observed, along with a CK-MB increase of up to 30 U/L, compared to the first week. This observation enforces the presumption that the increase in CK-MB enzyme level is related to the sustained training over the four weeks period, and does not represent a health problem.

BODY COMPOSITION ANALYSIS

In Fig. 1, the results recorded by the BOD POD show a decrease of 1.6 kg in total body mass over the 5 weeks.

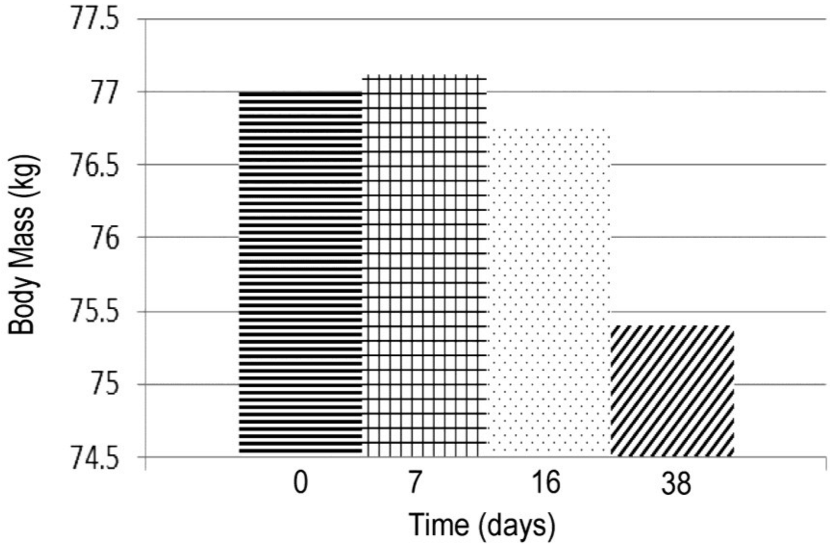

Fig. 1. Evolution of the total body mass, as measured using the BOD POD.

The lean mass, in turn, decreased by 0.3 kg, as seen in Fig. 2. However, during the training period, episodes of weight gain were observed. Given the biological variability of physiological parameters, we can conclude that the lean body mass has undergone natural oscillations and has virtually remained unchanged throughout the monitoring period.

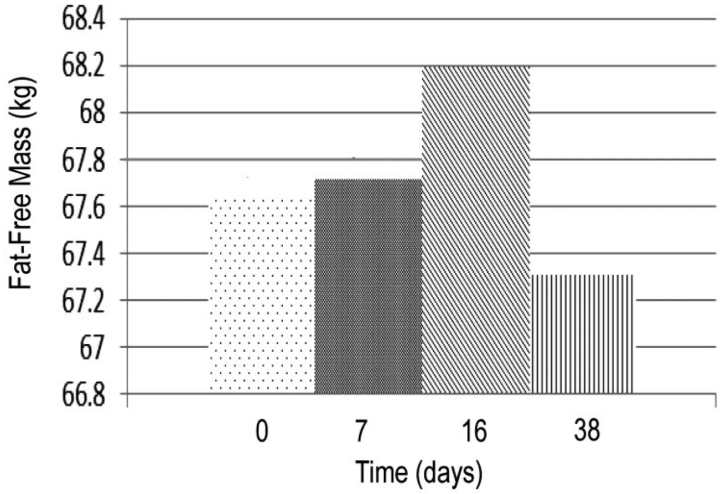

Fig. 2. Evolution of lean body mass (fat-free mass), as measured using the BOD POD.

Figure 3 shows the evolution of the amount of body fat during the program, revealing a significant reduction in body fat mass of about 1.3 kg.

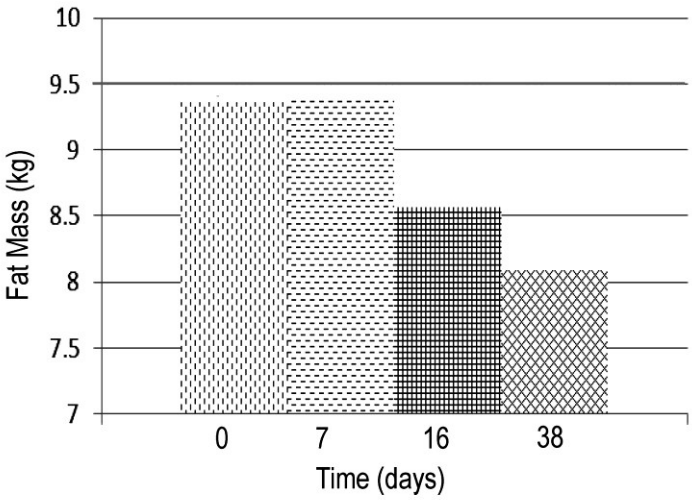

Fig. 3. Evolution of body fat mass, as determined from BOD POD measurements.

Figure 4 shows the change in per cent body fat as measured with the BodyMetrix device, using 4 different anthropometric estimation methods. Body fat percentage displays a steady drop as a result of a significant decrease in body fat mass.

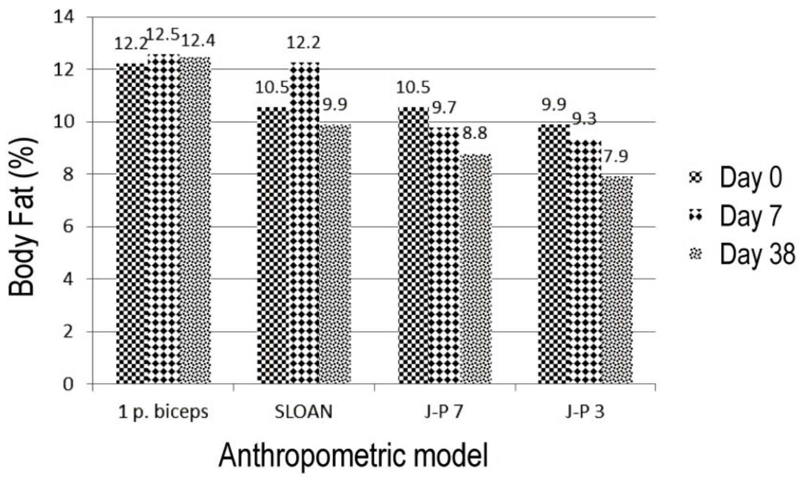

Fig. 4. The body fat percentage furnished by the Body Metrix instrument using 4 anthropometric models: 1 point biceps, Sloan [11], Jackson & Pollok with 7 sites (J-P 7) and Jackson & Pollok with 3 sites (J-P 3) [2].

Loss of subcutaneous fat is observed in Fig. 5, which represents the evolution of the adipose layer thickness beneath the skin, in different areas of the body.

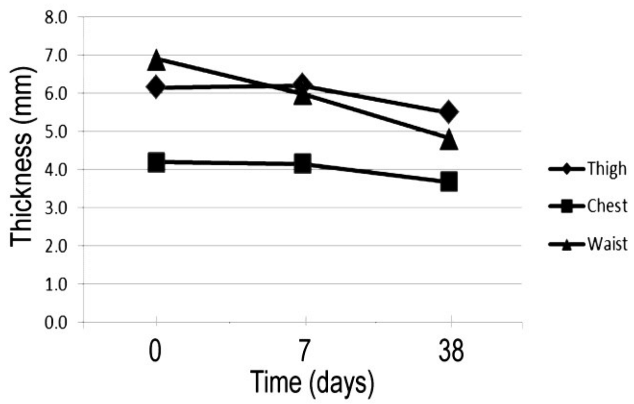

Fig. 5. Evolution of subcutaneous adipose tissue layer thickness on the thigh, chest and waist.

Remarkably, our training and nutrition plan caused a major decrease in subcutaneous adiposity in the abdominal region (see Fig. 5, triangular markers (Waist)).

At the same time, a slight increase in the net muscle mass was observed, which peaked in the fourth week of the study. The measured evolution of the muscle mass is illustrated in Fig. 6.

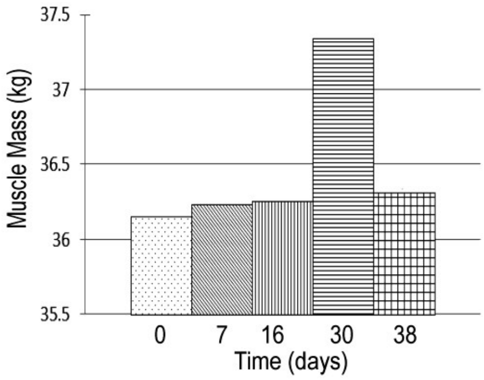

Fig. 6. The evolution of net muscle mass over the entire observation period, assessed *via* bioelectrical impedance measurements.

Figure 6 shows that, despite the decrease in body mass (Fig. 2), muscle mass was not lost during the study. On the contrary, it displayed a slight tendency to increase.

The value measured on day 30 is unusually high, suggesting that it is an outlier, stemming, perhaps, from an unusual state of subject hydration. Indeed, it is known that bioelectrical impedance analysis is sensitive to changes in body hydration and distribution (such as alterations of the ratio of extracellular water to intracellular water amounts) [3].

The comparative evolution of percent muscle mass and fat mass is shown in Fig. 7. The percent muscle mass was recorded using bioelectrical impedance analysis, whereas fat mass measurements were acquired using the BOD POD and BioMetrix devices.

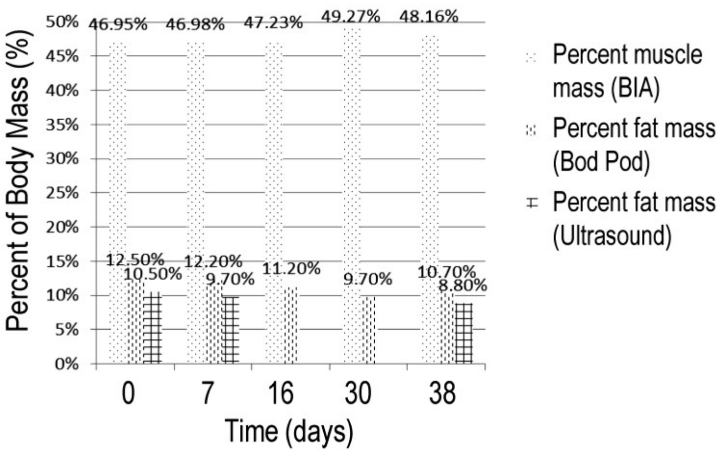

Fig. 7. Evolution of percent muscle mass assessed by BIA and percent fat mass measured using the BOD POD and ultrasound anthropometry.

CONCLUSIONS

Relying on body composition monitoring of one subject *via* three distinct methods (air displacement plethysmography, bioelectrical impedance analysis, and ultrasound anthropometry), our work demonstrates that it is possible to reduce the amount of body fat, while maintaining or even augmenting skeletal muscle mass.

According to the results reported here, an appropriate training program with a specific nutritional plan can elicit significant changes in body composition and in physical condition as a whole. The decrease in total body mass during this study resulted from the steady drop of fat mass, while muscle mass was conserved.

Blood tests results indicate that the use of a hyperproteic nutrition plan designed to maintain or develop muscle mass does present health risks.

The principles presented in this study may be useful for optimizing athletes' performance. Nevertheless, long-term maintenance of muscle mass is important also for people not involved in competitive activities, since it prevents muscular atrophy with aging.

By using personalized nutritional and sports programs, along with body composition assessments, it is possible to improve body constitution, thus improving physical performance and quality of life.

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