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Acute effects of resistance exercise on energy expenditure: revisiting the impact of the training variables

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ABSTRACT

The prevalence of obese and overweight persons is growing, both in Brazil and in other parts of the world. It is, therefore, important to establish strategies that will try to control this. The combination of energy restriction and aerobic exercises has long been recognized as an effective means of controlling body composition; on the other hand, the impact of resistance exercises on weight loss is still questionable. Thus, the purpose of this review was to discuss the effect of resistance exercises on energy expenditure, considering each of its related variables – intensity, duration, number of sets, interval between sets, movement velocity and type of training (circuit or multiple sets). The reviewed studies showed that resistance exercises may induce an acute increase in energy expenditure, through the energy cost of the exercise session itself and through the excess post-exercise oxygen consumption (EPOC). It is also recognized that the many variables related to resistance exercises influence the results in different ways. Number of repetitions, load, rest interval between sets and number of sets, when manipulated in order to increase volume or intensity, may significantly increase the energy expenditure of a typical exercise session. In general, considering all the limitations of the reviewed studies, the literature indicates that volume is the variable with greatest impact on energy expenditure during the training session, and that intensity has its largest impact on EPOC.

Key words: Calories. Indirect calorimetry. EPOC. Overweight. Exercise. Obesity.

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INTRODUCTION

Comprehension of the factors that affect energy balance is of key importance in understanding the regulation of body mass. Energy balance is determined, on the one hand, by energy consumption and, on the other, by energy expenditure. When these factors are not in equilibrium, it may result in an excessive accumulation or reduction of the energy stored endogenously as body fat. However, obesity is the most frequent result of the unbalance between food ingestion and energy expenditure.

The number of overweight persons has been increasing in Brazil and in many other parts of the world. Recent results revealed that, among the population residing in Rio de Janeiro, 44% of men and 33% of women between 26 and 45 year of age were overweight or obese[(1)].

Obesity, according to the World Health Organization[(2)], is considered a public health problem that leads to serious social, psychological and physical consequences, and is associated to greater risks of morbimortality by non-transmittable chronic diseases. Individuals with a body mass index equal to or above 30 $kg.m^{-2}$ are classified as obese[(2)]. Although the causes of this phenomenon are multifactorial[(3)] and therefore difficult to be established, the scientific community considers it wise to investigate ways to increase daily energy expenditure in order to reduce or control the prevalence of obesity.

Energy expenditure of physical activity is the most variable component of total energy expenditure. It can be voluntarily increased, contributing to a negative energy balance when food intake is also controlled[(4)].

Programs combining energy restriction and aerobic exercises have been, for a long time, indicated for weight loss[(5,6)]. This is justified by the role of physical activity in enhancing fat loss and minimizing reductions in lean mass observed during diet-only programs[7]. However, recent results indicate that, when food restriction is very severe, this combination may not be sufficient to avoid losses in lean body mass[4,8], consequently leading to a reduction in resting energy expenditure[9]. Lean body mass is the variable that mostly contributes to this component of total energy expenditure.

Resistance exercises have been recognized as an important component of a physical activity program for adults, leading to gains in muscular strength, resistance and power[10,11]. The increase in popularity of resistance training over the last two decades may be attributed to its health promotion benefits. Among these, one can emphasize its role in maintaining or increasing fat free mass[12,13] and resting metabolic rate, even when associated with hypo-energetic diets[8,14,15]. However, the real impact of resistance exercises on weight loss is still questionable due to evidence opposing those mentioned above[16,17], which leads to the belief that its major benefit would be mostly derived from the increase in daily energy expenditure related to the cost in performing the exercise[17,18].

Thus, the purpose of this review was to discuss energy expenditure of resistance exercises, considering each of its related variables – intensity, duration, number of sets, interval between sets, movement velocity and type of training (circuit or multiple sets).

DAILY ENERGY EXPENDITURE AND PHYSICAL ACTIVITY

Total energy expenditure is made up of three components: resting metabolism, diet-induced thermogenesis (DIT), and physical activity. Resting metabolic rate (RMR) is defined as the energy expenditure necessary to maintain the physiological processes in the post-absorptive state and, depending on the level of physical activity, may represent approximately 60 to 70% of total energy expenditure. DIT refers to the increase in metabolic rate above resting levels due to food intake and corresponds to approximately 10% of total energy expenditure. Physical activity is the most variable component and is related to the energy expenditure necessary for skeletal muscle activity. In sedentary individuals it represents approximately 15% of total energy expenditure, whereas in physically active individuals this can reach 30%[19].

All three components are subject to changes due to external factors and physical activity may cause acute and chronic increases in total energy expenditure. Acute increases would be due to the energy cost of performing the exercises in itself and of recovery after the exercise session, and chronic increases would be due to alterations in RMR[20]. The acute effects will be discussed below. For a review of chronic effects, the reader should refer to other papers available in the literature[21-24].

ENERGY EXPENDITURE OF RESISTANCE EXERCISES

The American College of Sports Medicine (ACSM)[10] recommends that resistance training with the aim of providing health benefits to the adult population should include at least one set of 8-12 repetitions of each one of 8-10 exercises involving the major muscle groups. Recently, in a position stand specifically aimed at resistance training, the ACSM[11] recommended greater intensities and volume for a training program that should be progressive and periodized, intended at improving muscular strength, hypertrophy and resistance.

The problem in studying the energy expenditure of resistance exercises seems to be the many different possibilities of combining exercises (those involving greater muscle mass incur in significantly larger energy expenditure[25]), number of sets, rest interval, number of repetitions, velocity of movement and load. Comparing the values obtained in the different studies becomes virtually impossible due to the great number of variables. In addition, individual characteristics such as gender, age, body composition and fitness level are considered potential intervening variables.

It should be mentioned that energy expenditure in males is always significantly higher than in females when performing similar resistance exercise protocols. This is caused by the larger free fat mass of males, compared to females. These differences become negligible when results are expressed as $kcal.kg^{-1}$ of free fat mass[26,27], demonstrating how gender and body composition are important in interpreting results.

Respiratory gas exchange measurement or indirect calorimetry is the most commonly used technique to estimate energy expenditure of physical activity, with a reported accuracy of –2% and 4%[28]. Therefore, this review included only studies that used this technique to measure energy expenditure of a resistance exercise session (table 1) and during its recovery (table 2).

1. Energy expenditure during a resistance exercise session

The energy expenditure during a resistance exercise session (consecutive multiple-set or circuit) has been investigated in a few studies, with results indicating a wide range of values, from 64 to 534 kcal[29-32].

During the seventies, Wilmore *et al.*[33] carried out the first study on this topic and found that trained men and women, aged 17 to 36 years, expended on average 131 kcal

TABLE 1
Net energy expenditure (EE) of a resistance exercise session

Authors	Subjects	Age (years)	Exercises protocol	EE ($kcal.min^{-1}$)
Wilmore *et al.*[33]	20 T M 20 T W	17-36 17-26	22,5 min, circuit, 10 exerc., 3 sets, 15-18 reps at 40% 1RM, 15 s int.	M: 5.8 W: 4.2
Ballor *et al.*[12]	40 UT obese W	33 ± 2	42 min, 8 exerc., 2 sets (10RM + 1 set max reps)	3,3
Ballor *et al.*[26]	20 T W 15 W T	25 ± 4 23 ± 4	37 min, circuit, 9 exerc., 3 sets, 30 s at 44% max, int. 1:1. Seeds: low, medium and fast	Low: H: 7.9; M: 5.2* Medium: H: 7.6; M: 5.1* Fast: H: 8.0; M: 5.0* (NS)
Pichon *et al.*[40]	8 M and W	23-34	4 exerc., 2 sets Circuit: 12 min, 20 reps at 47% 1 RM, 30 s int. Multiple-sets: 15 min, 10 reps at 69% 1 RM, 90 s int.	Circuit: 4.9* Multiple-sets: 4.5* (NS)
Burleson *et al.*[53]	15 T M	20-26	27 min, 8 exerc., 2 sets, 10 reps at 60% 1 RM, 1 min int.	6.4*
De Groot *et al.*[38]	9 UT M with CAD	54-75	Circuit, 6 exerc., 3 sets, 30 s sets (1) 18 min, 60% 1 RM, 30 s int. (2) 27 min, 60% 1 RM, 60 s int. (3) 18 min, 40% 1 RM, 30 s int. (4) 27 min, 40% 1 RM, 60 s int.	(1) 3.8; (2) 3.5; (3) 3.8; (4) 3.0 ($p < 0{,}05$ between condition 4 and the others)
Haltom *et al.*[39]	7 T M	27 ± 1	Circuit, 8 exerc., 2 sets, 20 reps at 75% 20RM. Two intervals: 20 s (duration 13 min) and 60 s (duration 23 min)	20 s: 8.5 60 s: 6.7 ($p < 0.05$)
Beckam and Earnest[27]	12 T M 18 T W	19-41 18-45	14 min, 5 exerc., using a weighted bar. Light: 1.4 kg to both genders; Moderate: M: 10.5 kg; W: 5.9 kg	M: Light: 5.0 Moderate: 6.2 W: Light: 3.6 Moderate: 4.1 ($p < 0.01$ between conditions)
Binzen *et al.*[31]	12 T W	24-34	45 min, 10 exerc., 3 sets, 10 reps at 70% 1RM, 1 min int.	2.3
Thornton and Potteiger[32]	14 T W	27 ± 5	9 exerc., 2 sets, 1min int. Two intensities: Light: 26 min, 15 reps at 45% 8 RM; Heavy: 23 min, 8 reps at 85% 8 RM	Light: 2.8 Heavy: 2.8 (NS)
Melanson *et al.*[58]	10 T M	31 ± 7	60 min + 10 min warm up, circuit, 10 exerc., 4 sets, 10 reps at 70% 1 RM (last set until fatigue), int. not reported	6.0
Hunter *et al.*[41]	7 T M	24 ± 4	29 min, 10 exerc., 1 min int. Multiple-sets: 2 sets, 8 reps at 65% 1 RM; *Super slow*: 1 sets, 8 reps at 25% 1RM	Multiple-sets: 3.9* *Super slow*: 2.5* ($p < 0.05$)
Phillips *et al.*[42]	6 T M 6 T W	27 ± 4	24 min, 8 exerc., 1 set, 15 RM, 2 min int.	M: 5.6 W: 3.4

M = men; W = women; T = trained; UT = untrained; CAD = coronary arterial disease; exerc. = exercises; reps = repetitions; int. = interval between sets.
* Calculated from the original report of O_2 net consumption multiplied by 5 kcal.

TABLE 2
Net energy expenditure (EE) during recovery from resistance exercise

Authors	Subjects	Age (years)	Exercises protocol	EE
Melby *et al.*[50]	6 T M	21-37	42 min, 7 exerc., 3 sets, 10 at 12 RM, 2 min int.	~19 kcal measured for 60 min
Olds and Abernethy[54]	7 T M	20-55	56 min, circuit, 7 exerc., 2 sets, 3.5 min int. Heavy: 12 reps at 75% 1RM Light: 15 reps at 60% 1RM	Heavy: 39 ± 40 kcal Light: 31 ± 33 kcal (NS between conditions) EPOC lasted 60 min
Melby *et al.*[29]	7 T M	20-40	96 min, 10 exerc., 5 sets, 70% 1RM, 4 min int.	35 ± 6 kcal measured for 2 hours
Burleson *et al.*[53]	15 T M	20-26	27 min, 8 exerc., 2 sets, 10 reps at 60% 1RM, 1 min int.	51 kcal* measured for 30 min
Haltom *et al.*[39]	7 T M	27 ± 1	Circuit, 8 exerc., 2 sets, 20 reps at 75% 20RM. Two intervals between sets: 20 s (13 min session) and 60 s (23 min session)	20 s: 52 ± 3 kcal 60 s: 37 ± 2 kcal ($p < 0.05$) measured for 60 min
Binzen *et al.*[31]	12 T W	24-34	45 min, 10 exerc., 3 sets, 10 reps at 70% 1RM, 1 min int.	31 kcal* measured for 60 min
Thornton and Potteiger[32]	14 T W	27 ± 5	9 exerc., 2 sets, 1 min int. Heavy: 23 min, 8 reps at 85% 8RM; Light: 26 min, 15 reps at 45% 8RM	Heavy: 11 ± 2 kcal Light: 6 ± 1 kcal ($p < 0.05$) EPOC lasted between 60 and 105 min
Schuenke *et al.*[51]	7 T M	19-26	Circuit, 31 min, 3 exerc., 4 sets, Max reps with 10RM load, 2 min int.	EE not reported EPOC lasted for 38 h

M = men; W = women; T = trained; UT = untrained; exerc. = exercises; reps = repetitions; int. = interval between sets.
* Calculated from the original report of O_2 net consumption multiplied by 5 kcal.

and 95 kcal, respectively, during a 22-minute circuit of light exercises.

Many other investigations were carried out on the following decades, most of which with non-athletes and, consequently, using exercise intensities much lower than those employed in competitive training. However, a study with Olympic weight lifters[25] showed that the energy expenditure during a typical training session of preparatory phase was approximately 392 kcal (11 kcal.min^{-1}). These values were much higher than those reported for non-athletic samples of resistance training experienced subjects (approximately 6 kcal.min^{-1}). It should be pointed out, though, that the latter study has serious limitations in relation to the description of variables important to the exercise protocol, such as intensity, number of sets and total volume. In addition, energy expenditure was measured during the periods of activity, and excluded the rest intervals between sets. There is also no mention as to whether the results represent net or gross values, which hinders the understanding of the results and comparisons to other studies.

The factors that most contribute to the energy expenditure of aerobic activity are duration and intensity[34]. Chad and Wenger[35], when exposing young adults of both genders to cycling at 70% of $\dot{V}O_2$max during 30, 45 and 60 min, found that energy expenditure showed a linear relationship with exercise duration. Net energy expenditure was approximately 10.6 kcal.min^{-1} for all three conditions (values obtained by multiplying O_2 consumption (in litres) by 5 kcal).

It is not possible to measure the effect of duration alone in a multiple-set resistance exercise session. To do so, it would be necessary to manipulate the rest interval between sets, which would eventually influence intensity and/or total work (defined here as the product of number of repetitions and load). It is known that as the rest interval between sets decreases, the relative intensity increases[36,37].

Nevertheless, it was possible to study the effect of duration during a session of circuit weight training. Results showed that the rest interval between stations was directly related to total oxygen consumption ($L.min^{-1}$), i.e. protocols with longer rest intervals required longer time to be performed and, consequently, greater absolute $\dot{V}O_2$ for the exercise session[26,38,39]. It should be pointed out, though, that these studies showed serious threats to external validity as the number of repetitions (20RM), the time in each station (5 to 40 s), and the low intensity (40 to 60% of 1RM) used for testing were far from those recommended for gains in muscular strength and hypertrophy[10,11].

In a comparison between circuit and continuous multiple-set resistance exercise protocols, Pichon *et al.*[40] observed higher energy expenditure for the circuit workout. However, the two protocols in this study varied not only in protocol, but also in volume, number of repetitions, intensity and interval between sets, jeopardizing any comparison. It is interesting to note that the intensity of the exercise was relevant in determining energy expenditure, since intensity:total work ratio was larger for the traditional protocol (greater intensity and smaller volume than for the circuit protocol). But this result is also difficult to interpret, since energy expenditure was calculated adding that of the exercise session to that of the first minutes of recovery. Thus, it is possible that intensity had a greater impact on the recovery period than during the exercise session. Due to the study design, it was not possible to isolate the effect of exercise intensity on the session itself.

The effects of intensity on energy expenditure have not been well investigated, but it seems that they are more pronounced during recovery from exercise[32]. Traditional resistance exercises of different intensities, but same total volume, seem to demand the same amount of energy, at least in trained young females[32].

Another variable that has not been properly investigated is movement velocity. Hunter *et al.*[41] demonstrated that the energy expenditure of an exercise session using isotonic equipment and performed with super-slow velocity (10 s concentric phase; 5 s eccentric phase) was only 69% of that of a traditional resistance exercise session with the same duration. This difference can probably be accounted for by the smaller total work of the super-slow protocol. On the other hand, Ballor *et al.*[26] reported that energy expenditure was independent of movement velocity, comparing exercise protocols with equal duration and, similarly, lower volume for the slower velocities.

Comparison of these two studies that investigated movement velocity is limited by the fact that, in the first study, intensity was different for the two protocols, and, in the second, exercises were performed in a circuit and using hydraulic equipment. This would lead one to consider that physiological responses may be due not only to velocity and total volume, but also to the type of protocol (circuit or multiple-set), the equipment used, and probably movement efficiency.

Recently, Phillips and Ziuraits[42] measured the energy expenditure required to perform one set of eight resistance exercises, as recommended by ACSM[10] to promote health benefits for adults, and demonstrated that this protocol was adequate in terms of intensity (around 4 METs – moderate intensity). However, the energy expenditure of the exercise session was considered low (approximately 135 kcal for males and 82 kcal for females), showing the need to complement this protocol. The authors suggested including one or two exercises involving large muscle groups for men. For women, they suggested performing two sets, instead of one, in order to achieve the minimum recommendation of 150 kcal of daily energy expenditure provided for by physical exercises.

In summary, if volume is really the variable with greatest impact on energy expenditure of resistance exercise (as seems to be the case for isotonic exercises), this would mean that there is no need to use high intensities when the aim is to increase energy expenditure. This would apply to untrained or overweight individuals and, although not specifically referring to resistance training, there is evidence that high-intensity exercise programs are related to low adherence in this population[43].

Table 1 summarizes the studies that investigated energy expenditure during a resistance exercise session.

2. Excess post-exercise oxygen consumption (EPOC)

After exercise, oxygen consumption remains elevated above resting levels for a certain period of time, showing increased energy expenditure during this period. This extra oxygen consumption is called EPOC. Although this phenomenon is well recognized, its magnitude, duration and metabolic bases need to be better understood, and so do the effects of the different variables related to physical exercises.

In relation to aerobic exercises, it has long been known that energy expenditure may remain elevated for more than 12 hours after the end of exercise on a cycle-ergometer[44,45], resulting in an additional expenditure of 73 to 150 kcal[46,47]. Duration and intensity of the exercise are considered to interfere in the magnitude if the responses, where the relation to EPOC is linear for duration and exponential for intensity[46-48].

However, Chad and Wenger[35] observed that increasing the duration of the activity (cycle-ergometer at 70% of $\dot{V}O_2$max during 30, 45 or 60 min) also resulted in an exponential increase in EPOC. These authors also found that energy expenditure during EPOC increased approximately twice after 45 min of activity and more than five times after 60 min, when compared to 30 min. These findings are unique in the literature, since these same authors and others[46,49] had already reported that EPOC increased linearly with duration of exercise at 70% of $\dot{V}O_2$max. In addition, it should be pointed out that the sample studied by Chad and Wenger[35] was made of only five subjects and of both genders (two males and three females).

More recently, investigations have focused on the effect of resistance exercise on EPOC and a wide range of results have been found (ranging, on average, from 6 to 114 kcal during 60 min to 15 h after the end of exercise)[29,31,32,50]. Even more surprising results were seen by Schuenke *et al.*[51], who studied trained young men after a circuit-resistance exercise session and observed that EPOC remained significantly above resting values during 38 h after termination of the activity. The important contribution of this study relies in the fact that resting O_2 consumption was measured on the day preceding the exercise measurements, but on the same time of day when EPOC was measured. In this way, possible differences due to variances in circadian energy expenditure were ruled out.

Once again, as mentioned above on the session on energy expenditure during the exercise session, the wide differences found in EPOC are due to the many possible combinations of the variables involved in resistance training. These many combinations make it difficult to compare and interpret results from different studies. However, the literature indicates that certain variables may have effects on EPOC different from those reported earlier in relation to energy expenditure of the exercise session.

Some researchers compared the impact of resistance and aerobic exercises, and showed that resistance exercises may result in a significantly larger EPOC[52].

Burleson *et al.*[53] compared duration and magnitude of EPOC in a typical resistance exercise session with that of aerobic exercises with same duration (27 min) and intensity (approximately 44% of $\dot{V}O_2$max). Results showed that oxygen consumption remained significantly elevated up to 90 min after terminating the resistance exercises and only 30 min after the aerobic activity. EPOC was significantly higher during the first 30 min after resistance exercises (19 litres) than after the aerobic exercise (12.7 litres), representing an additional expenditure of 95 and 64 kcal, respectively.

The variable with greatest impact on EPOC seems to be intensity and, in view of the current knowledge, only one study[54] contradicts this affirmative.

With the objective of investigating the effects of intensity on EPOC, Thornton and Potteiger[32] tested 14 trained young women in two conditions with resistance exercises of same volume and same intra-set rest intervals. The high intensity group (23 min, 8 reps at 85% of 8RM) was shown to have a significantly higher EPOC than the low intensity group (26 min, 15 reps at 45% of 8RM), similar to responses to aerobic exercise[47].

Testing the effect of rest intervals between stations of a circuit-resistance exercise session on EPOC, Haltom *et al.*[39] showed that the short interval (20 s) protocol resulted in a significantly higher EPOC than the long one (60 s). This also demonstrates the effect of intensity on EPOC, since rest interval between sets is one of the variables that determines the intensity of resistance exercise[36,37]. The authors further noted that it was the fast component of EPOC that was mostly influenced by the shorter rest interval between exercises.

The metabolic factors responsible for EPOC are still not clear, but it is known that there is a fast and a slow component. The fast component lasts only a few minutes and is mostly related to the elevation of blood lactate concentration[31] and to muscle creatine rephosphorylation [55]. The slow component is mostly related to the magnitude of anaerobic metabolism during exercise.

High intensity activities result in a greater activation of the sympathetic nervous system[56], which in turn results in a post-exercise increase in lipid metabolism in response to changes in the substrate predominantly used for energy production (from carbohydrate during intense activity to lipids during recovery). One of the most important factors responsible for the higher energy expenditure seen for many hours after intense activity is stimulus of the triacylglycerol-fatty acid cycle in adipose tissue. Additionally, other aspects to be considered are glycogen resynthesis[52], tissue injury and the effects that lead to muscle hypertrophy as a result of resistance training[57], which may also cause greater energy expenditure.

Increase in lipid oxidation in response to resistance exercise is another factor that should be considered due to its importance in weight management. Various studies reported a significantly lower respiratory exchange ratio compared to that measured before exercise or in control groups, which means a greater utilization of fat for energy production during the hours post-exercise[29,31,48].

However, Melanson *et al.*[58] demonstrated that 24-h fat oxidation (measured in a calorimetry chamber) was not statistically different between days when subjects performed aerobic or resistance exercises and no exercise, the control situation. Based on this evidence, it would seem that the greater fat oxidation reported in some studies may not represent a real long term increase in the use of lipids as energy substrate. Most studies restricted measurement of the respiratory exchange ratio to a few minutes immediately post-exercise.

There are fewer studies on the duration of EPOC than on its magnitude. Melby *et al.*[29] observed that the RMR of trained young males remained significantly elevated for 15 hours after a resistance exercise session comprising of seven exercises, three sets of 10-12RM and two-minute intervals between sets. This represented an energy expenditure of approximately 100 kcal. The authors concluded that the greatest impact on the magnitude and duration of EPOC was the high intensity.

Table 2 summarises the information from investigations on the energy expenditure during recovery from resistance exercise sessions.

In summary, EPOC resulting from a single resistance exercise session does not represent a great impact on energy balance; however, its cumulative effect may be relevant. Depending on exercise selection, intensity and frequency of training, summation of energy expended during recovery may be important in increasing total energy expenditure, thus contributing to management or reduction of body weight.

CONCLUSION

Based on current knowledge and considering all variables related to resistance training, it is still not possible to determine the best exercise protocol in order to substantially increase energy expenditure. New studies are needed to investigate the effects of movement velocity and of the combination of aerobic and resistance exercises. Further, it is important to establish the effects of individual characteristics, such as nutritional status, age, gender, body composition and fitness level on energy expenditure of resistance exercise. New studies should control these variables in order to isolate the contribution of each one to the energy expenditure of resistance exercise. Considering all limitations of the reviewed studies, the literature indicates that the variables that mostly influence energy expenditure of resistance exercise are volume and intensity, during the exercise session itself and EPOC, respectively.

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REFERENCES

1. Sichieri R, editor. Epidemiologia da obesidade. Rio de Janeiro: Eduerj, 1998.
2. World Health Organization. Obesity: preventing and managing the global epidemic. Geneva: World Health Organization, 1998.
3. Bouchard C. Can obesity be prevented? Nutr Rev 1996;2:S125-30.
4. Ballor DL, Harvey-berino JR, Ades PA, Cryan J, Calles-Escandon J. Contrasting effects of resistance and aerobic training on body composition and metabolism after diet-induced weight loss. Metabolism 1996; 45:179-83.
5. Wilmore JH. Body composition in sports and exercise: directions for future research. Med Sci Sports Exerc 1983;15:21-31.
6. Hagan RD, Upton SJ, Wong L, Whittam J. The effects of aerobic conditioning and/or caloric restriction in overweight men and women. Med Sci Sports Exerc 1986;18:87-94.
7. Ballor DL, Poehlman EC. Exercise-training enhances fat-free mass preservation during diet-induced weight loss: a meta-analytical finding. Int J Obes 1994;18:35-40.
8. Bryner RW, Ullrich IH, Sauers J, Donley D, Hornsby G, Kolar M, et al. Effects of resistance vs. aerobic training combined with an 800 calorie liquid diet on lean body mass and resting metabolic rate. J Am Coll Nutr 1999;18:115-21.
9. Henson LC, Poole DC, Donahoe CP, Heber D. Effects of exercise training on resting energy expenditure during caloric restriction. Am J Clin Nutr 1987;46:893-9.
10. American College of Sports Medicine. Position stand: The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 1998;30:975-91.
11. American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. Med Sci Sports Exerc 2002;34: 364-80.
12. Ballor DL, Katch VL, Becque MD, Marks CR. Resistance weight training during caloric restriction enhances lean body weight maintenance. Am J Clin Nutr 1988;47:19-25.
13. Ross R, Pedwell H, Rissanem J. Response of total and regional lean tissue and skeletal muscle to a program of energy restriction and resistance exercise. Int J Obesity 1995;19:781-7.
14. Svendsen OL, Hassager C, Christiansen C. Effects of an energy-restrictive diet, on lean tissue mass, resting metabolic rate, cardiovascular risk factors, and bone in overweight postmenopausal women. Am J Med 1993; 95:131-40.
15. Ryan AS, Pratley RE, Elahi D, Goldberg AP. Resistive training increases fat-free mass and maintains resting metabolic rate despite weight loss in postmenopausal women. J Appl Physiol 1995;79:818-23.
16. Kraemer WJ, Volek JS, Clark KL, Gordon SE, Incledon T, Puhl SM, et al. Physiological adaptations to a weight-loss dietary regimen and exercise programs in women. J Appl Physiol 1997;83:270-9.
17. Poehlman ET, Denino WF, Beckett T, Kinaman KA, Dionne IJ, Dvorak R, et al. Effects of endurance and resistance training on total daily energy expenditure in young women: a controlled randomized trial. J Clin Endocrinol Metab 2002;87:1004-9.
18. American College of Sports Medicine. Position stand: Appropriate intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 2001;33:2145-56.
19. FAO/OMS/UNU. Necessidades de energia e proteína: Série de relatos técnicos 724. Genebra: Organização Mundial da Saúde, 1998.

20. Hill JA, Melby C, Johnson SL, Peters JC. Physical activity and energy requirements. Am J Clin Nutr 1995;62:S1059-66.
21. Poehlman ET, Melby CL, Goran M. The impact of exercise and diet restriction on daily energy expenditure. Sports Med 1991;11:78-101.
22. Sjödin AM, Forslund AH, Westerterp K, Andersson AB, Forslund JM, Hambræus LM. The influence of physical activity on BMR. Med Sci Sports Exerc 1996;28:85-91.
23. Poehlman ET, Melby C. Resistance training and energy balance. Int J Sport Nutr 1998;8:143-59.
24. Ceddia RB. Composição corporal, taxa metabólica e exercício. Rev Bras Fisiol Exerc 2002;1:143-56.
25. Scala D, Mcmillan J, Blessing D, Rozenek R, Stone M. Metabolic cost of a preparatory phase of training in weight lifting: a practical observation. J Appl Sport Sci Res 1987;1:48-52.
26. Ballor DL, Becque MD, Katch VL. Energy output during hydraulic resistance circuit exercise for males and females. J Appl Sport Sci Res 1989;3:7-12.
27. Beckham SG, Earnest CP. Metabolic cost of free weight circuit weight training. J Sports Med Phys Fitness 2000;40:118-25.
28. Croonen F, Binkhorst RA. Oxygen uptake calculated from expiratory volume and analysis only. Ergonomics 1974;17:113-7.
29. Melby C, Scholl C, Edwards G, Bullough R. Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. J Appl Physiol 1993;75:1847-53.
30. Hunter GR, Wetzstein CJ, Fields DA, Brown A, Bamman MM. Resistance training increases total energy expenditure and free-living physical activity in older adults. J Appl Physiol 2000;89:977-84.
31. Binzen CA, Swan PD, Manore M. Postexercise oxygen consumption and substrate use after resistance exercise in women. Med Sci Sports Exerc 2001;33:932-8.
32. Thornton K, Potteiger JA. Effects of resistance exercise bouts of different intensities but equal work on EPOC. Med Sci Sports Exerc 2002;34: 715-22.
33. Wilmore JH, Parr RB, Ward P, Vodak PA, Barstow TJ, Pipes TJ, et al. Energy cost of circuit weight training. Med Sci Sports Exerc 1978;10: 75-8.
34. Hunter GR, Weinsier RL, Bamman MM, Larson DE. A role for high intensity exercise on energy balance and weight control. Int J Obes 1998; 22:489-93.
35. Chad KE, Wenger HA. The effect of exercise duration on the exercise and post-exercise oxygen consumption. Can J Spt Sci 1988;13:204-7.
36. Larson GD, Potteiger JAA. Comparison of three different rest intervals between multiple squat bouts. J Strength Cond Res 1997;11:115-8.
37. Abdessemed D, Duché P, Hautier C, Poumarat G, Bedu M. Effect of recovery duration on muscular power and blood lactate during the bench press exercise. Int J Sports Med 1999;20:368-73.
38. DeGroot DW, Quinn TJ, Jertzer R, Vroman NB, Olney WB. Circuit weight training in cardiac patients: determining optimal workloads for safety and energy expenditure. J Cardiopulm Rehabil 1998;18:145-52.
39. Haltom RW, Kraemer RR, Sloan RA, Hebert EP, Frank K, Tryniecki JL. Circuit weight training and its effects on excess postexercise oxygen consumption. Med Sci Sports Exerc 1999;31:1613-8.
40. Pichon C, Hunter GR, Morris M, Bond RL, Metz J. Blood pressure and heart rate response and metabolic cost of circuit versus traditional weight training. J Strength Cond Res 1996;10:153-6.
41. Hunter GR, Seelhorst D, Snyder S. Comparison of metabolic and heart rate responses to super slow vs. traditional resistance training. J Strength Cond Res 2003,17:76-81.
42. Phillips WT, Ziuraits JR. Energy cost of the ACSM single-set resistance training protocol. J Strength Cond Res 2003;17:350-5.
43. Pollock ML. Prescribing exercise for fitness and adherence. In: Dishman R, editor. Exercise adherence – its impact on public health. Champaing, Ill: Human Kinetics, 1988;259-77.
44. DeVries HA, Gray DE. After effects of exercise upon resting metabolic rate. Res Q 1963;34:314-21.
45. Maehlum S, Grandmontagne M, Newsholme EA, Sejersted OM. Magnitude and duration of excess postexercise oxygen consumption in healthy young subjects. Metabolism 1986;35:425-9.
46. Bahr R, Ingnes I, Vaage O, Sejersted OM, Newsholme EA. Effect of duration of exercise on excess postexercise O_2 consumption. J Appl Physiol 1987;62:485-90.
47. Bahr R, Sejersted OM. Effect of intensity of exercise on excess postexercise O_2 consumption. Metabolism 1991;40:836-41.
48. Phelain JF, Reinke E, Harris MA, Melby CL. Postexercise energy expenditure and substrate oxidation in young women resulting from exercise bouts of different intensity. J Am Coll Nutr 1997;16:140-6.
49. Chad KE, Wenger HA. The effect of duration and intensity on the exercise and post-exercise metabolic rate. Aust J Sci Med Sports 1985;17: 14-8.
50. Melby CL, Tincknell T, Schmidt WD. Energy expenditure following a bout of non-steady state resistance exercise. J Sports Med Phys Fitness 1992;32:128-35.
51. Schuenke MD, Mikat P, Mcbride JM. Effect of an acute period of resistance exercise on excess post-exercise oxygen consumption: implications for body mass management following a bout of heavy resistance exercise. Eur J Appl Physiol 2002;86:411-7.
52. Elliot DL, Goldberg L, Kuel KS. Effect of resistance training on excess post-exercise oxygen consumption. J Appl Sport Sci Res 1992;6:77-81.
53. Burleson MA, O'Bryant HS, Stone MH, Collins MA, Triplet-McBride T. Effect of weight training and treadmill exercise on post-exercise oxygen consumption. Med Sci Sports Exerc 1998;30:518-22.
54. Olds TS, Abernethy PJ. Postexercise oxygen consumption following heavy and light resistance exercise. J Strength Cond Res 1993;7:147-52.
55. Gaesser GA, Brooks GA. Metabolic bases of excess post-exercise oxygen consumption: a review. Med Sci Sports Exerc 1984;16:29-43.
56. Pratley R, Nicklas B, Rubin M, Miller J, Smith A, Smith M, et al. Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. J Appl Physiol 1994;76:133-7.
57. Vierck J, O'Reilly B, Hossner K, Antonio J, Byrne K, Bucci L, Dodson M. Satellite cell regulation following myotrauma caused by resistance exercise. Cell Biol Int 2000;24:263-72.
58. Melanson EL, Sharp TA, Seagle HM, Donahoo WT, Grunwald GK, Peters JC, et al. Resistance training and aerobic exercise have similar effects on 24-h nutrient oxidation. Med Sci Sports Exerc 2002;34:1793-800.