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Maximal fat oxidation rate in women with sedentary behaviour and at-risk body fat percentage

Máxima tasa de oxidación de grasas en mujeres con comportamiento sedentario y porcentaje de grasa riesgoso para la salud

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ABSTRACT

The purpose of this study was to examine how the maximal fat oxidation rate is affected in two groups of women with different fat mass percentages. Thirty-four women with sedentary behavior (aged 18–25 years) were divided into 2 groups according to their body fat percentage. (<32% of body fat was considered as a threshold following American College Sport Medicine [ACSM] indications). Body fat percentages were assessed by anthropometry, then subjects performed an adapted graded exercise test on a treadmill to determine maximal oxygen consumption and fat oxidation rates during exercise. There were significant differences (p<0.05) in maximal cardiorespiratory capacity (34.4±4.4 vs 30.4±10.4 mL x kg-1 x min-1) and maximal fat oxidation rates (0.39±0.05 vs 0.31±0.06 g x min-1) between the lower risk group when compared to the higher risk group. There was no correlation between body fat percentage (BF%) and fat oxidation rates in both groups. In conclusion, cardiorespiratory capacity and substrate oxidation are different when two groups of women divided by ACSM recommendations are considered and these results could help clinicians and trainers to prevent weight gain and/or promote body fat and body weight loss.

Key words: Exercise; Fatmax; Intensity; Obesity; Overweight.

RESUMEN

El propósito de este estudio fue examinar el cambio de la tasa de oxidación de grasas en dos grupos de mujeres con dife-

rentes porcentajes de masa grasa. Metodología: Treinta y cuatro mujeres con comportamiento sedentario (edades de 18 a 25 años) fueron divididas en dos grupos de acuerdo con su porcentaje de masa grasa (<32% fue considerado como umbral siguiendo las indicaciones del American College Sport Medicine [ACSM]). El porcentaje de masa grasa fue medido por antropometría y luego los sujetos realizaron una prueba adaptado en trotadora eléctrica para determinar el consumo máximo de oxígeno y las tasas de oxidación durante el ejercicio. Resultados: Existieron significativas (p<0,05) en la capacidad cardiorrespiratoria (34,4±4,4 vs 30,4±10,4 mL x kg-1 x min-1) y máxima tasa de oxidación de grasas (0,39±0,05 vs 0,31±0,06 g x min-1) entre el grupo de menor riesgo cuando se compara con el de mayor riesgo. No hubo correlación entre el porcentaje de masa grasa (BF%) vs oxidación máxima de grasas. Conclusión: la capacidad cardiorespiratoria y la oxidación de sustratos fue diferente cuando dos grupos de mujeres son divididos por las consideraciones de la ACSM.
Palabras clave: Ejercicio; Fatmax; Intensidad; Obesidad; Sobrepeso.

INTRODUCTION

Obesity is a major risk factor for cardiovascular disease (CVD) and thus has a significant impact on an individual's quality of life[1,2]. Overweight and obesity are defined as an excessive accumulation of fat that can be harmful to health. These conditions arise due to an imbalance between energy supply (i.e. from food) and demand (i.e. for exercise), based on genetic and environmental factors[3,4].

During prolonged exercise, carbohydrates and lipids are the primary substrates that fuel aerobic adenosine triphosphate (ATP) synthesis[5]. The relative utilization of these substrates during exercise can vary enormously and depends heavily on exercise intensity. For this reason, the ability of the human body to use carbohydrates and lipids is relevant for metabolism, body weight control, and body composition[6,7] especially, in people with cardiovascular risk. It has been found that people with sedentary behavior have elevated serum levels of fatty acids[8,9], in addition to a lower capacity for transporting and oxidation of fatty acids when compared with a healthy population[10].

The relationship between exercise intensity and lipid oxidation is parabolic during aerobic exercises, in that an initial increase in lipid oxidation is followed by a decrease in oxidation as exercise intensity increases[11,12]. The point at which fat oxidation reaches maximum and begins to decline is referred to as the crossover point. Exercise intensities that exceed the crossover point (~65% VO2max) utilize carbohydrates as the predominant fuel source for energy supply[13].

On the other hand, maximal fat oxidation (FatMax) during exercise reflects the fat oxidation machinery and, since changes in maximal fat oxidation are related to mitochondrial fat oxidation capacity, it could be used as a marker of metabolic fitness[14,15,16]. Due to limitations within fatty acid transport across the cell and mitochondrial membranes, fat oxidation is limited at higher exercise intensities.

In a large cohort of active people, the FatMax rate ranges between 0.18 and 1.27 g/min, and this can be reached at 47% to 75% of the maximal oxygen consumption (VO_2max). Furthermore, a study in a heterogeneous population determined oxidation rates to be between 0.18–1.01 g/min[17].

The FatMax rate for lean women is 0.35±0.12 g/min and for obese/overweight women 0.16±0.05 g/min, this can be reached at 50±10% to 61± 10% of the maximal oxygen consumption (VO_2max), respectively[8]. These broad values reflect the diversity of physiological responses involved and differences between subjects. It is frequently mentioned in the literature that the level of training, the intensity and duration at which it is performed, and the nutritional status of an individual could directly affect performance in a stress test which modifies the FatMax[18,19].

Multiple studies have identified considerable differences in FatMax and the intensity at which this is achieved in men and women; however, most research has focused mainly on determining the FatMax rates of men and there has been less research evaluating women[8,11,20]. Compared with previous research conducted on men, women had a higher fat oxidation rate at the same exercise intensity after training than men[21,22]. This finding suggests that muscle and adipose tissue metabolism may be different in men and women. Indeed, several physiological factors could underpin these differences and they are reflected in a wide range of performances during exercise.

In addition, little is known about the contribution of body composition to maximal fat oxidation rates, especially in women. Some reports have found that elevated fat mass promotes higher rates of fat oxidation[23,24]. Since body fat percentages for women fall under a few different categories, it is important to consider its classification for clinical purposes[19]. Some charts will subdivide body fat percentages based upon body type for different cohorts, such as athletes and average individuals, while other classifications subdivide the ranges by age[25,26]. Other researchers propose that a body fat percentage of over 32% in women is a risk factor for health and is a parameter that needs to be evaluated during exercise planning in order to reduce negative outcomes[27,28,29,30]. However, it is not completely clear how this group of women will reach FatMax when considering the increase of body fat percentage and the limitations that occur when increasing exercise intensity. Thus, this study aimed to analyze differences in maximal fat oxidation rates in women with different body fat levels, helping trainers and health professionals to prescribe more effective exercise programs in order to prevent weight gain and promote both reduced body fat and overall body weight.

MATERIAL AND METHODS

We used an experimental design to examine the influence of body fat percentage on the determination of the maximal rate of fat oxidation in women with sedentary behavior. The study was approved by the Research Ethics Committees of the Universidad Católica de la Santísima Concepción, Chile (reference project number: DINREG 06/2018) and was conducted in accordance with their ethical standards and the Declaration of Helsinki.

Experimental Approach

A total of 34 women were studied between 18 and 25 years of age and data collection was carried out in the Laboratorio de Kinesiología Aplicada of the Universidad Católica de la Santísima Concepción (UCSC). All subjects were recruited via social networks from a university population.

To reduce the influence of food consumption on the substrate response during exercise, subjects were instructed to maintain their normal diet throughout the study. On the first day of testing, the participants were measured for height, weight and body composition. The subjects then performed an exercise test to exhaustion as described below.

Eligibility criteria

The following groups were ineligible for this study: subjects who consumed medications that modify aerobic performance such as β-blockers, insulin, bronchodilators and anti-inflammatory agents, injuries or musculoskeletal diseases that prevent exercise, people who suffer from physical, sensory or cognitive disability, people with a history of cardiopulmonary disease or acute or chronic inflammatory conditions, cancer, acquired immune deficiency syndrome or diabetes mellitus, and pregnant women. The level of physical activity was measured using the long-form version of the Global Physical Activity Questionnaire (GPAQ) to confirm sedentary behavior as reported previously[31]. Testing was performed after the subject signed an informed consent in accordance with UCSC protocols for human experimentation.

Anthropometry

Total body weight and height were assessed using a scale with a Polar Balance (1G Polar, USA) and a built-in stadiometer (DETECT 2391), recording the results in kilos and meters respectively. The penta-compartmental component strategy was used to determine body composition (fat, muscle, bone, skin, and residual masses). Eight skinfolds, 3 bone diameters and 7 perimeters were measured using the anthropometry technique suggested by the International Society for the Advancement of Kinanthropometry (ISAK, Norton & Olds 1996).

Women with equal or greater than 32% body fat were considered part of the higher-risk group, and women with less than 32% body fat were considered part of the lower-risk group in accordance with ACSM criteria[32].

Indirect calorimetry and fat oxidation rates calculation

Participants were asked to refrain from vigorous exercise for 24 hours and fast for at least 10 hours before the FATmax test. The maximum oxygen consumption and fat oxidation rates were obtained through an incremental test on a treadmill to the point of exhaustion, using a protocol previously described for this purpose[33]. A short familiarization trial was conducted before starting the warm-up on the treadmill in order to explain and discuss all aspects related to the machine and protocols. There was a brief warm-up exercise consisting of walking at 3.5 km/h with an incline of 1% for 3 minutes, followed by a 2-minute break. The analysis of pulmonary volumes (respiratory oxygen uptake and carbon dioxide production) was carried out with an Oxycon Mobile cardiopulmonary stress testing system (Jaeger Oxycon Mobile®), which was calibrated with standard gas before each test. To this end, volumes were obtained in liters per minute, and the VO_2max was considered when subjects reached the criteria previously described[34,35]. Changes in metabolic rates were obtained at the end of every minute through the equation[36]:

$$\text{Oxidation rates } (g \cdot min^{-1}) = 1{,}67 \cdot VO_2 (L \cdot min^{-1}) - 1{,}67 \cdot VCO_2 (L \cdot min^{-1})$$

The value 1.67 is derived from the volume of VO_2 and VCO_2 from oxidation of 1 g of fat and the exercise intensity at which the highest rate of fat oxidation occurred was defined as the FATmax.

Data collection and statistical analysis

Data was digitized in Microsoft Excel 2007 software, and the information was exported to SPSS version 19.0 software for statistical analysis. Exploratory data analysis was carried out with the use of the central tendency measures (arithmetic and medium mean) and dispersion (minimum, maximum and standard deviation). A normality test (Shapiro-Wilk) was applied for the subsequent comparison (Student t test) with a statistical significance level $p<0.05$. Pearson correlation coefficient (r) was used to evaluate the existence of connection between fat oxidation rates and body fat percentages.

RESULTS

General and physical characteristics of the 34 women studied are shown in table 1. There were significant differences between the lower-risk and higher-risk groups in most of the physical and anthropometric variables (weight, BMI, body fat percentage and VO_2max).

There was a significant difference in FatMax rates between the lower- (0.39±0.05) and higher-risk group (0.318±0.634; $p< 0.001$). Maximal fat oxidation occurred at an exercise intensity of 50.1±5% and 40.2±6.4; ($p< 0.001$) of the VO_2max for the lower-risk and higher-risk groups, respectively (Table 2).

There was a significant difference between exercise intensity that elicited maximal fat oxidation rate between the lower-risk and higher-risk groups, and both rates occurred at two different exercise intensities ($p<0.05$). Significant differences were observed in fat oxidation rates at various exercise intensities for the lower-risk and higher-risk groups (20%, 40% and 60% of the VO_2max) (Figure 1). There was no significant relationship between body fat mass and the maximal rate of fat oxidation in both low and high-risk groups (Table 3).

Table 1. Participant characteristics.

	Low-risk (n= 19)	High-risk (n= 15)
Age (y)	20.6±1.4	22.4±2.0
Weight (kg)	58.6±7.8	65.3±10.4*
Height (m)	1.64±0.62	1.63±0.80
BMI (kg x m^{-2})	22.6±2.6	27.6±5.7**
BF%	26.4±4.1	34.8±2.2**
VO_2max (mL x kg^{-1} x min^{-1})	34.4±4.4	30.4±10.4*

BMI: body mass index, BF%: body fat percentage, VO_2max: maximal oxygen consumption.
Student's t test for independent samples: *p<0.05; **p<0.001. Values are represented as mean±SD.

Table 2. Maximal fat oxidation rate and VO_2max by category.

	Low-risk (n= 19)	High-risk (n= 15)
FatMax rate (g x min^{-1})	0.397±0.05	0.318±0.6**
VO_2max at FatMax	50.1±5%	40.2±6.4%**

FatMax rate: Maximal Fat oxidation rate, VO_2max: maximal oxygen consumption. Student's t test for independent samples: *p<0.05; **p<0.001. Values are represented as mean±s.d.

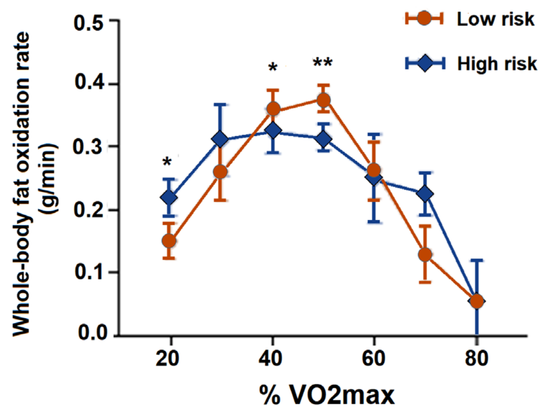

Figure 1: Fat oxidation rates vs. relative exercise intensities VO_2max during a treadmill test. *p<0.05, **p<0.01. t-tests were used to compared between groups. Values are means±SD.

Table 3. Relationship between body fat mass and maximal fat oxidation rate.

	Correlation (r)	p
Low-risk (n= 19)	0.74	0.54
High-risk (n= 15)	0.11	0.22

DISCUSSION

The purpose of the present study was to examine the differences in fat oxidation rates in two groups of women with different body fat levels. The results indicate that women in the high-risk group have a lower FatMax compared to those in the low-risk group. This finding supports the idea that people with higher body fat percentages may suffer from metabolic inflexibility during exercise[37]. In addition, this maximal fat oxidation rate was found to occur at a 0.397% intensity and this result demonstrates a lower capacity for women with a high fat percentage to oxidate fat, a response which has been observed in similar studies[19,38]. Other groups have reported that overweight middle-aged women (51±6 years) reached their FATmax around 52% VO_2max in similar tests[39]. The result is contrary to other research where there were no significant differences in the maximal fat oxidation rate and exercise intensity that elicited that rate between the lower- and higher-fat groups of women[19,40]; however, several investigations have demonstrated that body fat levels can specifically affect fat and carbohydrate oxidation[41,42].

The ability to oxidase fat has also been linked with body fat percentage, and in fact those with higher percentages also have a lower maximal oxygen consumption on the treadmill test; the latter showing a direct relationship with the subjects' inability of achieving a higher exercise intensity. As expected, VO_2max were low in all obesity groups. In fact, during an incremental test, changes are observable in physiological parameters for obese subjects such as the inability to augment ventilation and the ability to manage the increased oxygen requirements during exercise; these alterations are also due to the biomechanical issues correlated to the movement of the obese subjects[43].

On the other hand, the high-risk group started with a higher fat oxidation when compared to the low-risk group. This difference indicates an accelerated response of the human body to face the increase in energy demand which tends to be stable around 50% of the VO_2max. After 50% of the VO_2max, a decrease in oxidation occurred in both groups, showing an exchange in substrate oxidation from fat to carbohydrate in order to sustain the metabolic demands[44]. However, the data indicates no correlation between body fat mass and maximal oxidation rates as it has been seen previously in other studies[17,19].

This study did not consider those with CV risk, such as subjects with type III obesity; indeed, some studies showed that this group has the highest maximal fat oxidation when compared with other groups[9,26,43]. It is important to note that this study used the International Society for the Advancement of Kinanthropometry (ISAK) standards for obtaining anthropometry data, but it could be possible to improve the quality of this information as the higher the fat mass, the lower the sensitivity of the test. Comparison among studies with individuals of different body composition and fitness levels indicates that increased body fat and inactivity are associated with lower exercise intensity corresponding to FatMax. The average intensity at FatMax was 48% VO_2max in a large population group with body fat around 20-25%[17], while exercise intensity corresponding FatMax was as low as 40% in a group of obese individuals, which was also demonstrated in our study.

We suspect that improving the cardiorespiratory fitness of people with high body fat percentage may also increase their ability to oxidase fat during exercise, which could have important clinical implications.

The present findings should be interpreted with caution given the relatively small number of obese women in the sample. Furthermore, fat oxidation rates were only determined in a treadmill exercise test; future studies should replicate this study using different methods to obtain a better understanding.

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REFERENCES

1. *Lahey R, Khan SS. Trends in obesity and risk of cardiovascular disease. Curr Epidemiol Rep. 2018; 5: 243-251.*
2. *Lee SJ, Shin SW. Mechanisms, pathophysiology, and management of obesity. N Engl J Med. 2017; 376: 1491-1492.*
3. *Abdelaal M, le Roux CW, Docherty NG. Morbidity and mortality associated with obesity. Ann Transl Med. 2017; 5: 161.*
4. *Freitag Luglio H. Genetic variation of fatty acid oxidation and obesity, a literature review. Int J Biomed Sci. 2016; 12: 1-8.*
5. *Mul JD, Stanford KI, Hirshman MF, Goodyear LJ. Exercise and regulation of carbohydrate metabolism. Prog Mol Biol Transl Sci. 2015; 135: 17-37.*
6. *Willoughby D, Hewlings S, Kalman D. Body composition changes in weight loss: Strategies and Supplementation for maintaining lean body mass, a brief review. Nutrients. 2018; 10: 1876.*
7. *Ormsbee MJ, Bach CW, Baur DA. Pre-exercise nutrition: the role of macronutrients, modified starches and supplements on metabolism and endurance performance. Nutrients. 2014; 6: 1782-1808.*
8. *Lanzi S, Codecasa F, Cornacchia M, Maestrini S, Salvadori A, Brunani A, et al. Fat oxidation, hormonal and plasma metabolite kinetics during a submaximal incremental test in lean and obese adults. PLoS One. 2014; 9: 88707.*
9. *Lanzi S, Codecasa F, Cornacchia M, Maestrini S, Capodaglio P, Brunani A, et al. Short-term HIIT and Fat max training increase aerobic and metabolic fitness in men with class II and III obesity. Obesity (Silver Spring). 2015; 23: 1987-1994.*
10. *Bonen A, Luiken JJ, Glatz JF. Regulation of fatty acid transport and membrane transporters in health and disease. Mol Cell Biochem. 2002; 239: 181-192.*
11. *Maunder E, Plews DJ, Kilding AE. Contextualising maximal fat oxidation during exercise: Determinants and normative values. Front Physiol. 2018; 9: 599.*
12. *Zurbuchen A, Lanzi S, Voirol L, Trindade CB, Gojanovic B, Kayser B, et al. Fat oxidation kinetics is related to muscle deoxygenation kinetics during exercise. Front Physiol. 2020; 11: 571.*
13. *Purdom T, Kravitz L, Dokladny K, Mermier C. Understanding the factors that affect maximal fat oxidation. J Int Soc Sports Nutr. 2018; 15: 3.*
14. *Wang J, Tan S, Cao L. Exercise training at the maximal fat oxidation intensity improved health-related physical fitness in overweight middle-aged women. J Exerc Sci Fit. 2015; 13: 111-116.*
15. *Pillard F, Van Wymelbeke V, Garrigue E, Moro C, Crampes F, Guilland JC, et al. Lipid oxidation in overweight men after exercise and food intake. Metabolism. 2010; 59: 267-274.*
16. *Montes-de-Oca-García A, Perez-Bey A, Corral-Pérez J, Velázquez-Díaz D, Opazo-Díaz E, Fernandez-Santos JR, et al. Maximal fat oxidation capacity is associated with cardiometabolic risk factors in healthy young adults. Eur J Sport Sci. 2020: 1-11.*
17. *Venables MC, Achten J, JeukendrupAE. Determinants of fat oxidation during exercise in healthy men and women: A cross-sectional study. J Appl Physiol (1985). 2005; 98: 160-167.*
18. *Astorino TA, Schubert MM. Changes in fat oxidation in*

response to various regimes of high intensity interval training (HIIT). Eur J Appl Physiol. 2018; 118: 51-63.
19. Blaize AN, Potteiger JA, Claytor RP, Noe DA. Body fat has no effect on the maximal fat oxidation rate in young, normal, and overweight women. J Strength Cond Res. 2014; 28: 2121-2126.
20. Croci I, Borrani F, Byrne NM, Byrne N, Wood RE, Wood R, et al. Reproducibility of Fatmax and fat oxidation rates during exercise in recreationally trained males. PLoS One. 2014; 9: 97930.
21. Achten J, JeukendrupAE. Optimizing fat oxidation through exercise and diet. Nutrition. 2004; 20(7-8): 716-727.
22. Melanson EL, MacLean PS, Hill JO. Exercise improves fat metabolism in muscle but does not increase 24-h fat oxidation. Exerc Sport Sci Rev. 2009; 37: 93-101.
23. Yun HY, Lee T, Jeong Y. High-fat diet increases fat oxidation and promotes skeletal muscle fatty acid transporter expression in exercise-trained mice. J Med Food. 2020; 23: 281-288.
24. Özgünen KT, Özdemir Ç, Korkmaz-Eryılmaz S, Kılcı A, Günaştı Ö, Kurdak SS. A Comparison of the maximal fat oxidation rates of three different time periods in the FatMax stage. J Sports Sci Med. 2019; 18: 44-51.
25. Tomlinson DJ, Erskine RM, Morse CI, Onambélé GL. Body fat percentage, body mass index, fat mass index and the ageing bone: Their singular and combined roles linked to physical activity and diet. Nutrients. 2019; 11: 195.
26. Phillips CM, Tierney AC, Perez-Martinez P, Defoort C, Blaak EE, Gjelstad IM, et al. Obesity and body fat classification in the metabolic syndrome: Impact on cardiometabolic risk metabotype. Obesity (Silver Spring). 2013; 21: 154-161.
27. Lohman TG. Body Composition methodology in sports medicine. Phys Sportsmed. 1982; 10: 46-58.
28. Ferguson B. ACSM's Guidelines for Exercise Testing and Prescription 9th Ed. 2014, Philadelphia. 2014.
29. Keim NL, Belko AZ, Barbieri TF. Body fat percentage and gender: Associations with exercise energy expenditure, substrate utilization, and mechanical work efficiency. Int J Sport Nutr. 1996; 6: 356-369.
30. Tucker LA, Thomas KS. Increasing total fiber intake reduces risk of weight and fat gains in women. J Nutr. 2009; 139: 576-581.
31. Cleland CL, Hunter RF, Kee F, Cupples ME, Sallis JF, Tully MA. Validity of the global physical activity questionnaire (GPAQ) in assessing levels and change in moderate-vigorous physical activity and sedentary behaviour. BMC Public Health. 2014; 14: 1255.
32. Mondal H, Mishra SP. Effect of BMI, body fat percentage and fat free mass on maximal oxygen consumption in healthy young adults. J Clin Diagn Res. 2017; 11: 17-20.
33. JeukendrupAE, Wallis GA. Measurement of substrate oxidation during exercise by means of gas exchange measurements. Int J Sports Med. 2005; 26 Suppl 1: S28-37.
34. Howley ET, Bassett DR, Jr., Welch HG. Criteria for maximal oxygen uptake: Review and commentary. Med Sci Sports Exerc. 1995; 27: 1292-1301.
35. Zapata-Lamana R, Henríquez-Olguín C, Burgos C, Meneses-Valdés R, Cigarroa I, Soto C, et al. Effects of polarized training on cardiometabolic risk factors in young overweight and obese women: A randomized-controlled trial. Front Physiol. 2018; 9: 1287.
36. Frayn KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. J Appl Physiol Respir Environ Exerc Physiol. 1983; 55: 628-634.
37. Mogensen M, Vind BF, Højlund K, Beck-Nielsen H, Sahlin K. Maximal lipid oxidation in patients with type 2 diabetes is normal and shows an adequate increase in response to aerobic training. Diabetes Obes Metab. 2009; 11: 874-883.
38. Alkahtani SA, King NA, Hills AP, Byrne NM. Effect of interval training intensity on fat oxidation, blood lactate and the rate of perceived exertion in obese men. Springerplus. 2013; 2: 532.
39. Heydari M, Freund J, Boutcher SH. The effect of high-intensity intermittent exercise on body composition of overweight young males. J Obes. 2012; 2012: 480467.
40. Arad AD, Basile AJ, Albu J, DiMenna FJ. no influence of overweight/obesity on exercise lipid oxidation: A systematic review. Int J Mol Sci. 2020; 21.
41. Estall JL, Kahn M, Cooper MP, Fisher FM, Wu MK, Laznik D, et al. Sensitivity of lipid metabolism and insulin signaling to genetic alterations in hepatic peroxisome proliferator-activated receptor-gamma coactivator-1alpha expression. Diabetes. 2009; 58: 1499-1508.
42. AstrupA, Buemann B, Christensen NJ, Madsen J, Gluud C, Bennett P, et al. The contribution of body composition, substrates, and hormones to the variability in energy expenditure and substrate utilization in premenopausal women. J Clin Endocrinol Metab. 1992; 74: 279-286.
43. Emerenziani GP, Ferrari D, Marocco C, Greco EA, Migliaccio S, Lenzi A, et al. Relationship between individual ventilatory threshold and maximal fat oxidation (MFO) over different obesity classes in women. PLoS One. 2019; 14: 215307.
44. Brun JF, Malatesta D, Sartorio A. Maximal lipid oxidation during exercise: a target for individualizing endurance training in obesity and diabetes? J Endocrinol Invest. 2012; 35: 686-691.