Short report

Effects of adipose tissue distribution on maximum lipid oxidation rate during exercise in normal-weight women

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Abstract

Aim. – Fat mass localization affects lipid metabolism differently at rest and during exercise in overweight and normal-weight subjects. The aim of this study was to investigate the impact of a low vs high ratio of abdominal to lower-body fat mass (index of adipose tissue distribution) on the exercise intensity (Lipoxmax) that elicits the maximum lipid oxidation rate in normal-weight women.

Methods. – Twenty-one normal-weight women (22.0 ± 0.6 years, 22.3 ± 0.1 kg.m−2) were separated into two groups of either a low or high abdominal to lower-body fat mass ratio [L-A/LB (n = 11) or H-A/LB (n = 10), respectively]. Lipoxmax and maximum lipid oxidation rate (MLOR) were determined during a submaximum incremental exercise test. Abdominal and lower-body fat mass were determined from DXA scans.

Results. – The two groups did not differ in aerobic fitness, total fat mass, or total and localized fat-free mass. Lipoxmax and MLOR were significantly lower in H-A/LB vs L-A/LB women (43 ± 3% VO2max vs 54 ± 4% VO2max, and 4.8 ± 0.6 mg min−1 kg FFM−1 vs 8.4 ± 0.9 mg min−1 kg FFM−1, respectively; P < 0.001). Total and abdominal fat mass measurements were negatively associated with Lipoxmax (r = −0.57 and r = −0.64, respectively; P < 0.01) and MLOR [r = −0.63 (P < 0.01) and r = −0.76 (P < 0.001), respectively].

Conclusion. – These findings indicate that, in normal-weight women, a predominantly abdominal fat mass distribution compared with a predominantly peripheral fat mass distribution is associated with a lower capacity to maximize lipid oxidation during exercise, as evidenced by their lower Lipoxmax and MLOR.

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Keywords: Women; Adipose tissue localization; Exercise; Metabolic fitness; Lipoxmax

Abbreviations: A/LB, abdominal to lower-body; ANP, atrial natriuretic peptide; BMI, body mass index; CHO, carbohydrate; DXA, dual X-ray absorptiometry; FFA, free fatty acids; FFM, fat-free mass; FM, fat mass; H-A/LB, high abdominal to lower-body; L-A/LB, low abdominal to lower-body; MAP, maximum aerobic power; MLOR, maximum lipid oxidation rate; NW, normal-weight; SD, standard deviation; VCO2, carbon dioxide production; VO2, oxygen consumption; VO2max, maximum oxygen consumption.

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1. Introduction

The exercise intensity that elicits the maximum lipid oxidation rate (MLOR) is termed Lipoxmax [1]. These two parameters are used to individualize training programmes for people with metabolic disorders wishing to maximize their lipid oxidation and decrease fat mass (FM) [1]. In addition, they are used to assess ‘metabolic fitness’, defined as aerobic fitness and skeletal muscle health [2]. Lipoxmax is influenced by training status, maturity, gender, and parameters of body composition such as total FM and fat-free mass (FFM) [1,3]. In fact, Lipoxmax occurs at a lower rate of maximum oxygen consumption (VO2max) and is accompanied by a lower MLOR in obese compared with normal-weight (NW) subjects [1].

Adipose tissue localization is one factor affecting energy metabolism independently of total FM [4]. In NW and obese subjects, the abdominal fat depot is preferentially associated with metabolic disorders such as insulin resistance and dyslipidaemia, whereas peripheral FM is considered as a protective factor against cardiometabolic risk in the long term [5,6]. During exercise, greater increase in plasma free fatty acid (FFA) availability in obese women with lower-body fat compared with abdominal fat is indicative of greater stimulation of lipolysis in peripheral rather than central adipose tissue [7]. Our laboratory previously reported that NW women with a higher abdominal to lower-body (H-A/LB) FM ratio exhibited lowered lipid mobilization, oxidation and metabolic flexibility during submaximum exercise (45 min at 65% VO2max) than NW women with a low abdominal to lower-body (L-A/LB) FM ratio [4].

Greater ability to maximize lipid oxidation rate, elicited at higher relative exercise intensities, is likely to reflect a profile of ‘metabolic fitness’ [2]. Thus, in terms of primary prevention, investigation of Lipoxmax and MLOR in NW women with specific adipose tissue distributions appears to be relevant for individualizing training programmes to improve metabolic effects and/or diagnose subjects with impaired lipid oxidation. Whereas the impact of total FM on Lipoxmax and MLOR has been well documented in studies comparing obese and NW subjects, little is known of the effects of adipose tissue distribution in women within the NW range. The aim of the present study was therefore to investigate the impact of low and high A/LB FM ratios on MLOR and Lipoxmax in NW women.

2. Methods

2.1. Population

Twenty-one recreationally active NW women (between 2 to 4 h/week of physical activity), with a mean age of 22.0 ± 0.6 years, were studied. All subjects were premenopausal and NW, with body mass index (BMI) values within the healthy weight range (BMI > 19.5 but < 25 kg.m⁻², 22.4 ± 2.5 kg.m⁻²) and waist circumferences ≤80 cm. As there is no standard for the A/LB FM ratio in premenopausal lean women, ratios were calculated for the whole population (n = 21; 0.80 ± 0.1, range: 0.56–1.06). Based on the median (0.78), women were allocated to two groups: one with an L-A/LB FM ratio < 0.78 (n = 11; 0.68 ± 0.08, range: 0.56–0.77); and the other with an H-A/LB FM ratio > 0.78 (n = 10; 0.90 ± 0.1, range: 0.82–1.06). More detailed descriptions of the study population have been previously published [4].

The study was approved by the local ethics committee (Comité de Protection des Personnes Sud Est VI, AU818) and complied with the Helsinki declaration. Every woman signed an informed consent form to participate and attended the laboratory on two separate occasions.

2.2. Experimental design

Before inclusion, an initial screening interview and physical examination, including anthropometric measurements and body composition assessment, were performed. A second session was arranged to determine their Lipoxmax, MLOR and VO2max.

2.2.1. Abdominal to lower-body fat-free mass and fat mass ratios

Dual-energy X-ray absorptiometry (DXA) scans were visually analyzed by an experienced technician who delineated the region of interest between vertebral bodies L1 and L4 to determine abdominal FM (visceral and subcutaneous adipose tissue). The uppermost limit was set by a horizontal line going through the T12/L1 vertebral space, and the lowermost limit was set by a horizontal line going through the L4/L5 vertebral space. Lower-body FM was similarly determined using DXA scans, with the iliac crest as the uppermost limit of the lower limbs [4].

The A/LB FM ratio was calculated as: A/LB FM ratio = abdominal FM (g)/lower-body FM (g). Likewise, the A/LB FFM ratio was calculated from FFM located in the abdominal region of interest and lower-body FFM.

2.2.2. Lipoxmax, MLOR and VO2max

Exercise tests were performed on an electromagnetically braked cycle ergometer (Ergoline, Bitz, Germany). Respiratory gas exchanges (VO2, VCO2) were measured breath by breath through a mask connected to O2 and CO2 analyzers (Oxycon Pro-Delta, Jaeger, Hoechberg, Germany).

Lipoxmax expressed as a percentage of VO2max, MLOR and carbohydrate (CHO) oxidation (mg.min⁻¹.kg FFM⁻¹) were determined in a fasting state during 6 min stages of graded exercise. The exercise test started at 20% of the predicted maximum aerobic power (MAP) with 10% MAP increments (up to 60% of MAP), and was followed by a rapid incremental test until VO2max and MAP were reached [1,8]. During the last minute of each stage (from the fifth to sixth minute), VCO2 and VO2 values were recorded and used to calculate the respective CHO and lipid oxidation rates [9].

The relationship between power output and lipid oxidation rates displays a bell-shaped curve. Smoothing of this curve enabled calculation of exercise intensity (Lipoxmax) at the point of MLOR [8].
2.3. Statistical analysis

All statistical analyses were carried out with STATISTICA version 8.00 software (StatSoft, Tulsa, OK, USA). Results are expressed as means ± standard deviation (SD). Normality of distribution was tested with the Kolmogorov–Smirnov test. Physiological and anthropometric characteristics, Lipoxmax and MLOR were compared between groups with unpaired t tests. Group effects on CHO oxidation were assessed by one-way analysis of variance (ANOVA) with repeated measures. Pearson’s correlation analysis was performed to establish the presence of correlations in the entire studied population between (1) anthropometric characteristics and Lipoxmax or MLOR, and (2) VO2max and FM ratios or Lipoxmax. Statistical significance was set at $P < 0.05$.

3. Results

Lipoxmax and MLOR during exercise were significantly lower ($P < 0.001$) in H-A/LB compared with L-A/LB women (Figs. 1A, B, E), whereas CHO oxidation rate was higher ($P < 0.05$) in H-A/LB than in L-A/LB women during exercise (Fig. 1F). Importantly, in H-A/LB vs L-A/LB women, except for A/LB FM ratio and waist circumference ($0.90 ± 0.1$ vs $0.68 ± 0.08$ ($P < 0.001$), and $77.0 ± 4.6$ vs $74.0 ± 2.6$ ($P < 0.01$), respectively), the two groups did not differ in terms of VO2max ($49.8 \text{ mL\,min}^{-1}\text{kg\,FM}^{-1}$ ± $5.3$ vs $53.3 \text{ mL\,min}^{-1}\text{kg\,FM}^{-1}$ ± $6.2$ for H-A/LB vs L-A/LB women, respectively) or any other anthropometric characteristics (BMI: $23.4 \text{ kg}\cdot\text{m}^{-2}$ ± $2.6$ vs $21.3 \text{ kg}\cdot\text{m}^{-2}$ ± $2.2$; total FM: $27.8\% ± 3.5$ vs $25.6\% ± 4.6$; total FFM: $42.5 \text{ kg} ± 3.8$ vs $41.4 \text{ kg} ± 2.2$; and
A/LB FFM ratio: 0.17 ± 0.02 vs 0.16 ± 0.05 for H-A/LB vs L-A/LB women, respectively). Neither Lipoxmax nor FM ratio were significantly associated with VO2max.

Total and abdominal FM were negatively associated with Lipoxmax ($P < 0.01$) and MLOR ($P < 0.01$ and $P < 0.001$, respectively), with a stronger relationship observed with abdominal FM [$r = -0.64 (P < 0.01)$ and $r = -0.76 (P < 0.001)$ for Lipoxmax and MLOR, respectively] compared with total FM [$r = -0.57 (P < 0.01)$ and $r = -0.63 (P < 0.01)$ for Lipoxmax and MLOR, respectively] (Figs. 1C and D). No significant correlations were observed between total and localized FFM and lower-body FM and Lipoxmax or MLOR.

4. Discussion

The main result of this study was that H-A/LB NW women exhibited lower MLOR and Lipoxmax compared with L-A/LB NW women. Previously our laboratory had reported that H-A/LB NW women exhibited lower lipid oxidation rates and less metabolic flexibility during prolonged moderate-intensity exercise compared with L-A/LB women [4]. Thus, the present findings are complementary to our initial results and underline the fact that adipose tissue distribution in NW women alters MLOR during exercise.

As individuals who can oxidize more lipids during exercise are those who are better at losing weight [10], it may be hypothesized from our study that NW women who tend to store fat in the abdominal region have a limited ability to reach high fat oxidation rates during exercise, and this may increase their risk of future excess FM accumulation, insulin resistance and dyslipidaemia.

Our results are relevant in the field of energy metabolism as no study has previously investigated the impact of FM ratio on Lipoxmax and MLOR. A previous study reported differences in lipid oxidation rates after low-intensity training between upper-body obesity and lower-body obesity in women [11]. Lipoxmax and MLOR disparities between the two groups may partly explain these discrepancies. Furthermore, our present results suggest that FM distribution is a major determinant of gender differences in lipid oxidation during exercise [12].

Excess abdominal FM stimulates chronic lipolytic activity with lower glucose oxidation under resting conditions, thereby leading to insulin resistance [13,14]. Conversely, a greater ability to oxidize lipids during exercise is protective against metabolic disturbances. In our present study, the H-A/LB women displayed reduced flexibility of maximum fat utilization, which predisposes to potential metabolic disorders [15]. When our two groups were analyzed together, correlations between total or abdominal FM and Lipoxmax or MLOR further highlighted the adverse impact of abdominal FM on maximum lipid oxidation in NW subjects. Lower Lipoxmax and MLOR are characteristic of an unhealthy metabolic phenotype. Thus, NW women with a preferentially abdominal fat distribution may be at greater risk of the metabolic syndrome compared with NW women with a preferentially peripheral FM distribution [16].

Several hypotheses may explain our results. The decreases in glycerol, FFA, growth hormone and atrial natriuretic peptide (ANP) plasma levels, and increases in glycaemia and insulinemia, observed in our previous study [4] may partly explain both the reduced lipid oxidation rate during prolonged submaximum exercise and lower Lipoxmax and MLOR in H-A/LB women. This is corroborated by the positive correlations observed between lipid oxidation rate during submaximum exercise and FFA, glycerol, noradrenaline and ANP concentrations [4].

Raynaud et al. [17] reported that moderately overweight women with predominantly lower-body FM exhibited greater insulin sensitivity than those with predominantly trunk fat. Lipid accumulation is known to increase both insulin resistance and lipotoxicity. Thus, a greater ability to maximize the rate of lipid oxidation with lower CHO oxidation during exercise may be associated with greater insulin sensitivity.

From a methodological point of view, Lipoxmax presents some limitations, particularly when used for prescribing exercise-training programmes based on intraindividual variability. Also, training at Lipoxmax maximizes lipid oxidation during exercise but, conversely, limits glucose oxidation. It is well known that dyslipidaemia is involved in insulin resistance and, thus, maximizing lipid oxidation during exercise could act against these metabolic features.

To achieve a rate of fat oxidation similar to those measured during the exercise test, subjects should train in the fasted state, which may be a barrier in sedentary subjects. For this reason, the Lipoxmax may be considered an interesting diagnostic tool that may be used for planning exercise-training programmes under well-standardized conditions.

In conclusion, the present study indicates that FM distribution alters Lipoxmax and MLOR in NW women, with lower values observed in H-A/LB subjects. However, whether this reduced ability to maximize lipid oxidation during exercise in NW women with a predominantly abdominal FM distribution increases the risks for further obesity and the development of the metabolic syndrome requires further investigation.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.diabet.2014.02.006.
References


