

# Energy balance and energy expenditure in obesity — is obesity a disease of inactivity?

Estelle V Lambert (PhD)

Julia H Goedecke (BSc (Med) Hons Nutrition and Dietetics, PhD)

UCT/MRC Research Unit for Exercise Science and Sports Medicine, Department of Human Biology, University of Cape Town

## Abstract

The aim of this clinical review was to examine the problem of obesity in the context of energy balance, and specifically to examine the role of increased physical activity in altering energy balance in obese individuals. The control of obesity depends on a regulatory axis involving feedback control between: food intake, nutrient turnover, energy expenditure, and body fat stores. Physical activity impacts on this regulatory axis at all levels. There are four major conclusions regarding physical activity in the management of obesity: (i) a combination of physical activity and restriction of energy intake is more effective for weight loss than exercise or dieting, independently; (ii) physical activity may help to offset the loss of fat-free mass and attenuate the decline in metabolic rate that occurs with food energy restriction while dieting; (iii) exercise may be most beneficial for the prevention of weight regain after weight loss; and (iv) the impact of physical activity on body composition and body weight occurs in a dose-dependent manner. There is consensus that moderate intensity activity of approximately 45 - 60 min/day is required to prevent the transition to overweight or obesity. However, in order to lower the overall risk of chronic diseases of lifestyle, minimising co-morbidities of obesity and increasing adherence; the Centers for Disease Control and American College of Sports Medicine guidelines provide an evidence-based recommendation that 'every adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably, all days of the week'.

## CORRESPONDENCE:

Estelle V Lambert  
UCT/MRC Research Unit for Exercise Science and Sports Medicine  
Sports Science Institute of South Africa  
Department of Human Biology  
University of Cape Town  
PO Box 115  
Newlands 7725  
Phone/Fax: 021-650 4571/686 7530  
Email: [vlambert@sports.uct.ac.za](mailto:vlambert@sports.uct.ac.za)

## Introduction

As a consequence of the well-described, adverse metabolic sequelae associated with obesity, obesity is now internationally recognised as a disease entity.<sup>29</sup> It is often referred to as a nutritional disorder, and the result of a positive energy balance and consequent weight gain. We also recognise the possible existence of a 'thrifty phenotype', purported to develop as the result of genetic and environmental interactions, predisposing individuals to increased metabolic and feeding efficiency.<sup>8</sup> Finally, there is evidence that individuals may exhibit 'high fat' or 'low fat' phenotypes.<sup>3,28</sup> These have been described in persons with distinctly different patterns of macronutrient intake, who are weight-stable.

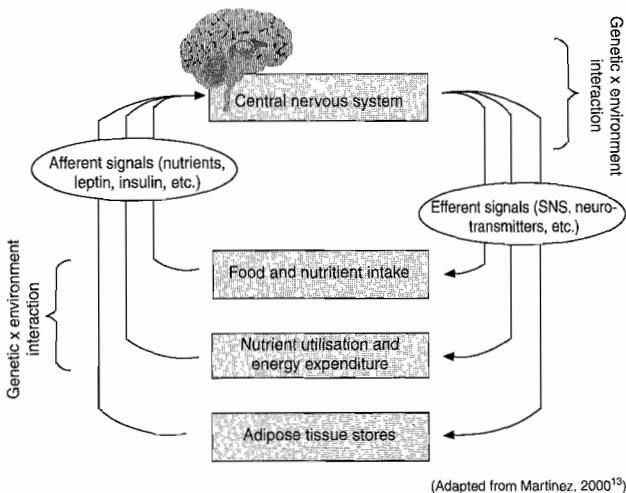
The question remains as to whether the obese individual is 'hypo-metabolic' and may be described as having a 'lower-than-expected' metabolic rate. Is this 'thriftness' part of genetic or intra-uterine programming? Alternatively, to what extent does over-nutrition or increased food energy and specific nutrient intake play a role in the aetiology of obesity in certain individuals? Alternatively, we may ask what adaptations have occurred in obese individuals who are weight-stable and in perfect energy and nutrient balance for their current intake and level of activity, in order for them to maintain their larger than average reservoir of adipose tissue?

The aim of this clinical review was to examine the problem of obesity in the context of energy balance, and specifically to examine the role of increased physical activity in altering energy balance in obese individuals.

## Obesity and energy balance

The obese individual who is weight-stable may be in perfect energy balance. Thus, the difference between lean and obese weight-stable persons is simply the 'degree of adiposity for which their energy intake adjusts itself to their energy expenditure'.<sup>6</sup> What is of clinical importance is to identify putative environmental factors that interact with a genetic susceptibility for obesity, causing this difference in body composition. In order for these individuals to lose weight a negative energy balance must be created by modifying one or another of these environmental or lifestyle risk factors.

Thus, the control of obesity depends on a regulatory axis for energy balance involving: food intake, nutrient turnover, energy expenditure, and body fat stores (Fig. 1).<sup>13</sup> The precision of body weight regulation (within 1 - 2% over a period of years), despite day-to-day variability in food intake and levels



**Fig. 1. Proposed regulatory axis providing feedback control for energy balance, modulated by genetic susceptibility.<sup>13</sup>**

of physical activity, provides indirect evidence for a robust system of feedback control. For example, food intake initiates afferent or sensory inputs, signalling the central nervous system to modulate appetite<sup>13</sup> and to adjust energy and nutrient metabolism. An acute bout of physical activity may up-regulate the sympathoadrenal response, suppress insulin, increase carbohydrate oxidation during exercise, as well as increase fat oxidation and decrease circulating leptin concentrations in the post-exercise period. The response of this regulatory axis will depend, in part, on the individual's nutritional status, adipose tissue stores and state of training.

This feedback control system is further modulated by the genetic x environment interaction. For example, dietary fat intake has been implicated as an aetiological factor associated with increased adiposity, and obesity has often been associated with a reduced rate of fat oxidation. Conversely, Blundell and Cooling<sup>3</sup> have recently described 'high-fat' and 'low-fat' phenotypes; normal-weight, young men who habitually choose a high- or a low- fat diet. Those with the high-fat intake have a concomitantly high rate of fat oxidation, and in fact a higher rate of resting energy expenditure.

There are conflicting data to suggest that obesity is associated with neuro-endocrine adaptations influencing both energy expenditure and substrate utilisation, and that individuals who are susceptible to obesity may have lower sympathetic nervous system activity and a lower dietary-induced thermogenesis.<sup>26</sup> There is also evidence that various metabolic adaptations occur in reduced-obese persons, suggesting that they may be at increased risk for subsequent weight gain.<sup>1,25</sup> The metabolic profile of the reduced-obese person includes reduced plasma leptin and insulin levels, reduced sympathetic nervous system activation, reduced metabolic rate, an attenuation in the thermic effect of feeding, increased lipogenic or fat-storing capacity of the adipocytes<sup>37</sup> and a reduced rate of fat oxidation. In one study, reduced-obese persons were shown to expend less energy in daily activities such as walking, even after accounting for the low-

ered body weight<sup>7</sup> The fact that the regulatory control of energy balance is altered in favour of an increased energetic efficiency and toward increased fat storage, despite weight loss in reduced-obese persons, suggests that altered sympathetic activation and other adaptations may have been causally associated with obesity.

## Physical activity and energy balance

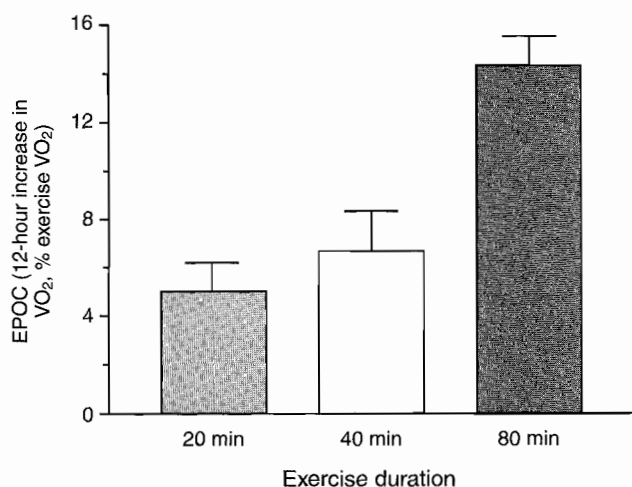
The most obvious role for physical activity and energy balance is the direct increase in energy expenditure resulting from an acute bout of exercise. Moderate, continuous activity, involving large muscle groups may increase energy expenditure approximately 250 - 350 kcal, over and above resting metabolic rate. The energy expenditure associated with physical activity is linked in a dose-dependent manner to the intensity and duration of the exercise bout (usually between 3 and 10 times higher than the resting energy expenditure).

In addition to this direct effect, exercise with increasing intensity may be associated with an elevation in metabolic rate lasting even up to several hours post-exercise, also depending on exercise duration and intensity. This effect is known as EPOC or excess post-exercise oxygen consumption. For example, in a study of healthy young men, exercising for more than an hour at 70% of their maximal oxygen consumption, energy expenditure remained significantly elevated for up to at least 12 hours post-exercise<sup>12</sup> (Table I<sup>23</sup>). In another study, exercise of increasing duration (from 20 to 80 minutes) resulted in a doubling of the increase in the post-exercise energy expenditure<sup>2</sup> (Fig. 2). There has also been an associated increase in fat oxidation during the post-exercise recovery period.<sup>2</sup>

However, at lower exercise intensities the increase in energy expenditure in the post-exercise period is transient, rapidly declining within 30 minutes to an hour following the exercise bout. Moreover, a reduction in food intake, even over a short period of time, may result in an attenuation of EPOC. The post-exercise increase in energy expenditure seen with high intensity exercise may also be reduced by the administration of propranolol, suggesting that this effect is due, in part, to beta-adrenergic stimulation.<sup>30</sup>

**TABLE I. Summary of the effects of increasing exercise intensity on energy balance (adapted from Tremblay *et al.*<sup>23</sup>)**

Effects of increasing exercise intensity	Reference
Increase in the magnitude and duration of the EPOC or energy expenditure.	Yoshioka <i>et al.</i> <sup>30</sup>
Increase in the oxidation of fat in the post-exercise recovery period.	Yoshioka <i>et al.</i> <sup>30</sup>
Greater loss of subcutaneous fat with exercise training.	Tremblay <i>et al.</i> <sup>24</sup>
Increase in the capacity of skeletal muscle to utilise fat for energy production.	Tremblay <i>et al.</i> <sup>24</sup>
Decrease in energy intake, and an increase in carbohydrate selection in the diet.	Imbeault <i>et al.</i> <sup>19</sup>
EPOC = excess post-exercise oxygen consumption.	



**Fig. 2. Increase in excess post-exercise oxygen consumption (EPOC) is linked to exercise duration at 70%  $VO_{2max}$  in healthy, young men.<sup>2</sup>**

The effects of exercise on energy balance extend beyond the immediate post-exercise effect. For example, exercise involving intermittent, high-intensity training for 15 weeks was compared with 20 weeks of endurance training. In this study, the overall energy cost of the endurance-training programme was more than twice that of the high-intensity programme (120 MJ vs. 58 MJ). Despite this, the loss of body fat, measured using subcutaneous skinfold thickness, was markedly greater following the high-intensity programme. Furthermore, in this study high-intensity training resulted in a greater increase in skeletal muscle enzymes involved in fat oxidation.<sup>24</sup> This finding appears counterintuitive, as high-intensity exercise is associated with increased carbohydrate oxidation and lower relative rates of fat oxidation; however, the absolute rate of fat oxidation is greater at higher exercise intensities (~65%  $VO_{2max}$ ).<sup>18</sup>

Regular exercise training has been consistently shown to attenuate the decrease in metabolic rate associated with dieting or food energy restriction.<sup>17,23</sup> This may be attributed, in part, to the maintenance of fat-free mass,<sup>17</sup> as fat-free mass is the single most important determinant of metabolic rate in both lean and obese individuals.<sup>16</sup> Moreover, an acute bout of exercise has been associated with a measurable increase in the thermic effect of feeding or energy expenditure associated with food intake, particularly in obese persons.<sup>22</sup> In addition, exercise of increasing intensity has been shown to be associated with a reduction in food intake, and an increase in the *ad libitum* selection of carbohydrate in the diet.<sup>10</sup>

However, it is not clear whether these relationships are also found in obese, exercising individuals. For example, there are studies that have shown a decrease in resting fat oxidation in reduced-obese persons. These studies may be confounded by weight loss, dietary change, and differences in fitness.<sup>9</sup>

### Physical activity in the prevention and management of obesity

Obesity is a chronic condition that is the result of a positive energy balance, irrespective of the individual's current state of energy balance. DiPietro<sup>4</sup> has examined the evidence from observational studies for the role of physical activity, or alternatively inactivity, on the prevention of subsequent weight gain (Table II). The results of these studies suggest that habitual physical activity attenuates age-related weight gain that would otherwise be expected in these cohorts. The consensus at the recent Mike Stock Conference in 2002 examining the question 'How much physical activity is enough to prevent unhealthy weight gain', was that 'moderate intensity activity of approximately 45 - 60 min/day is required to prevent the transition to overweight or obesity'.<sup>20</sup>

**TABLE II. Summary of epidemiological study findings examining the impact of physical activity on the primary and secondary prevention of obesity (extracted from DiPietro<sup>4</sup>)**

Population studied	Period of time/method	Results	Effect size
Middle-aged men (4 600 men and 724 women)	7.5-year follow-up, weight and fitness measured 3 times	Improvements in fitness attenuated weight gain, lowered the odds of weight gain 5 - 10 times	For each 1 min improvement in treadmill time, 0.60 kg less weight gain
Cohort of young men (1 823) and women (2 083)	7-year follow-up, weight and fitness measured 4 times	Decreases in fitness related to weight gain in both men and women	For each 1 min decline in treadmill time, 1.5 kg gain for men and 2.1 kg gain for women
Cohort of > 22 000 male doctors	Cross-sectional and 2-year follow-up	Higher baseline activity levels linked to lower risk of becoming overweight	For each 10 MET increase in weekly activity, a 0.30 unit decrease in BMI at follow-up
Cohort of > 121 000 women nurses	Prospective 2-year follow-up, self report activity and weight	Women who quit smoking and increased activity gained less weight than those who quit smoking.	Increase of 2.3 kg in women who quit smoking, vs 1.8 kg in those who quit and increased activity 8 - 16 METs/wk

MET = metabolic equivalent; BMI = body mass index.

Physical activity alone for the purpose of weight loss has been shown to be only moderately effective. A recent meta-analysis of weight loss research conducted over the past 25 years compared diet-only, exercise-only or diet-plus-exercise intervention.<sup>15</sup> Results suggest that short-term weight loss ( $\pm$  15 wks) was similar between diet-only and diet-plus-exercise groups ( $\sim$  10 - 11 kg), and better than that found with exercise-only. However, Ross *et al.*<sup>19</sup> recently demonstrated that physical activity without caloric restriction can reduce obesity and improve insulin sensitivity. They found that 12 weeks of approximately 60 minutes of daily physical activity without caloric restriction, producing a negative energy balance of approximately 700 kcal/day, resulted in substantial reductions in body weight (7.6 kg), total body fat (6.1 kg) and visceral fat (1 kg) in obese men. It appears that the failure of exercise to produce substantial weight loss may be due to inadequate energy expenditure, or alternatively, compensation resulting from an increased energy intake or reduced daily activity.

Physical activity may be more important in preventing weight regain after weight loss. Indeed, the results of the meta-analysis by Miller *et al.*<sup>15</sup> found that the maintenance of reduced weight at 1 year of follow-up was significantly more effective in the diet-plus-exercise group than diet-only group. Data collected on individuals in the National Weight Control Registry, who had lost  $\geq$  13.5 kg and maintained it for at least 1 year, demonstrated that weight maintenance is associated with high levels of physical activity.<sup>11,14,21</sup> Individuals who maintained their weight reported expending approximately 2 800 kcal/week through physical activity,<sup>11,14</sup> corresponding to 80 min/day of moderate activity or 35 min/day of vigorous activity.<sup>21</sup>

Based on current evidence, recommendations for physical activity for the prevention and management of obesity should ideally aim to create a negative energy balance, increased resting metabolic rate, increased sympathetic nervous system activation, increased rate of whole body fat oxidation, and increased fat-free mass. However, there is an important role for exercise, over and above any effects on energy balance in overweight persons. Regular physical activity has been shown to lower the overall risk for chronic diseases of lifestyle, minimising the co-morbidities of obesity, and increasing adherence to dietary management. The Centers for Disease Control and American College of Sports Medicine guidelines provide an evidence-based recommendation that 'every adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably, all days of the week'. Moderate-intensity activities are better tolerated than high-intensity exercise, especially by obese and older adults.<sup>26</sup> These guidelines have been shown to be as effective in increasing physical activity and cardiorespiratory fitness as the traditional, more prescriptive guidelines,<sup>5</sup> but are more effective in terms of long-term compliance.<sup>27</sup>

## Conclusion

In summary, the obese individual who is weight-stable may be in perfect energy balance. The control of obesity depends on a regulatory axis involving feedback control between food intake, nutrient turnover, energy expenditure,

and body fat stores. Physical activity impacts on this regulatory axis at all levels. An acute bout of exercise, of sufficient intensity stimulates the sympathoadrenal axis, and increases metabolic rate both during and in the post-exercise period. Long-term adaptations to exercise training include increased fat-free mass and increased activity of skeletal muscle enzymes involved in fat oxidation. However, studies suggest that a combination of physical activity and restriction of energy intake is more effective for weight loss than exercise or dieting, independently. This may be due to the fact that exercise may offset loss of fat-free mass and the attenuation of metabolic rate associated with food energy restriction or dieting. Finally, although conclusive data are lacking, there is consensus that moderate intensity activity of approximately 45 - 60 min/day is required to prevent the transition to overweight or obesity. Moreover, there is evidence that changes in body mass or body fat with exercise occur in a dose-dependent manner. Over and above the important impact of exercise on energy balance in overweight persons, exercise prescription should focus on lowering overall risk for chronic diseases of lifestyle, minimising co-morbidities of obesity, and increasing adherence.

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