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Invited Review

HIGHLIGHTED TOPIC | *Role of Exercise in Reducing the Risk of Diabetes and Obesity*

Role of physical activity in preventing and treating obesity

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Hill, James O., and Holly R. Wyatt. Role of physical activity in preventing and treating obesity. *J Appl Physiol* 99: 765–770, 2005; doi:10.1152/japplphysiol.00137.2005.—There is an inverse relationship between physical activity and weight gain. However, additional research is needed to quantify the amount of physical activity required to prevent weight gain in different populations, improve the way we convey physical activity recommendations to the public, and help the individuals increase their physical activity. Although physical activity does not appear to contribute significantly to weight loss, it is critical for maintenance of weight loss. Available data are consistent in that 60–90 min/day of moderate-intensity physical activity is required to maintain a significant weight loss. Although there is agreement about the need for high levels of physical activity to maintain weight loss, there is a need for more research to understand why physical activity is critical for weight loss maintenance. Finally, additional research is needed to determine whether there is an optimal level of physical activity below which it is difficult for most people to achieve a balance between energy intake and expenditure at a healthy body weight. The increasing prevalence of obesity may reflect the fact that the majority of the population has fallen below such a level of physical activity.

weight loss; weight maintenance; exercise

WE ARE IN THE MIDST OF AN epidemic of obesity, where over one-quarter of all adults are obese and another 35% are overweight (8, 24). Children are not faring much better because childhood obesity has tripled over the past three decades (25). Obesity has been recognized as one of our most serious public health challenges, and strategies for prevention and treatment of obesity are a high public health priority.

Understanding and addressing obesity begin with an understanding of energy balance. The weight gain that leads to obesity can only result from an energy imbalance, where energy intake exceeds energy expenditure over some period of time. Similarly, weight loss can occur only when energy expenditure is elevated above energy intake for a period of time. Finally, when energy intake is matched to energy expenditure, body weight remains constant. There is very little argument about the states of energy balance or imbalance that produce weight gain, weight loss, or weight stability, but there is considerable argument about the respective roles of diet and physical activity in achieving each of these energy balance goals. The intent of this paper is to summarize what we know and what we do not know about the role of physical activity in the prevention and treatment of obesity. This review will focus on human studies that relate physical activity to changes in body weight. There is extensive animal literature about impact of exercise on body weight and metabolism that will not be covered.

DEFINING OVERWEIGHT AND OBESITY

Currently, overweight and obesity are defined for the public on the basis of body mass index (BMI), which is determined by dividing weight in kilograms by height^2 in meters. A healthy BMI is defined as 18.5 to $<$25 kg/m^2. Overweight is defined as 25–29.9 kg/m^2, and obesity is a BMI $\geq$30 kg/m^2. Although BMI is highly correlated with percent body fat, it does not provide information about body composition. At any given BMI, individuals may vary in their actual amount of body fat.

ROLE OF PHYSICAL ACTIVITY IN PREVENTION OF OBESITY

The obesity epidemic seems to have arisen due to gradual weight gain in the population. Hill et al. (15), using longitudinal data from the Coronary Artery Risk Development in Young Adults (CARDIA) (20) and cross-sectional data from the National Health and Nutrition Examination Surveys (24), estimated the average weight gain of Americans to be 0.45–0.90 kg/yr, at least over the past decade. Similar gradual weight gain appears to be occurring in populations in other countries as well. Brown et al. (3) found that middle-aged Australian women are gaining an average of 0.5 kg/yr. The level of physical activity for an individual or a population may impact the amount of weight gain occurring over time.

Epidemiological studies. Results of epidemiological studies are consistent in that those who are physically active are less likely to gain weight over time than those who are not.

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Haapanen et al. (12) studied 2,695 women and 2,564 men over a 10-yr period from 1980 to 1990. Individuals were classified as follows: *1*) physically active throughout the 10 yr; *2*) physically activated, which the authors defined as no regular activity in 1980 but at least 1 time/week in 1990; *3*) physically inactivated, which the authors defined as at least 1 time/week in 1980 but not in 1990; and *4*) physically inactive throughout the 10 yr. They found that individuals who were either inactive throughout or who decreased physical activity from 1980 gained weight, whereas the other two groups maintained or lost weight. The odds of gaining ≥5 kg over this period were significantly higher in those who were inactive throughout or who decreased physical activity over the period.

DiPietro et al. (6) followed 3,075 men and women for an average of 5.2 yr. They calculated the physical activity level (PAL) for each participant at baseline and during follow-up. PAL is a way to express the amount of physical activity in multiples of daily resting metabolic rate. A PAL of 2.0 would be an amount of physical activity that increases total daily energy expenditure to twice that of resting metabolic rate. DiPietro et al. designated a PAL of 1.45 or less as low, 1.46–1.60 as moderate, and >1.60 as high. They found that the greatest weight gain was seen in individual who had a low PAL at both baseline and follow-up. Individuals who increased from a low to moderate PAL maintained a constant body weight over 10 yr, and those who increased from low to high lost weight.

Schmitz et al. (29) studied weight changes over a 10-yr period in CARDIA. They also calculated the number of exercise units for each participant on the basis of a 12-mo history of participating in 13 different physical activities. They found that change in physical activity was inversely correlated with change in body weight in all race (black and white) and sex subgroups (men vs. women).

Williamson et al. (35) examined 10-yr changes in body weight in subjects studied in the first National Health and Nutrition Examination Survey. They found that low levels of physical activity and recreation were strongly related to weight gain in both men and women. Recreational activity was inversely related to body weight. Men and women in the low-activity group were three to four times more likely than the more active group to experience weight gain.

Prospective studies. There are very few prospective, randomized trials examining the ability of physical activity to prevent weight gain. Such trials are sorely needed to establish a causal relationship between physical activity and prevention of weight gain and to identify how much physical activity is required to prevent weight gain. This amount may vary between populations and between life stages of individuals. For example, more physical activity may be required for prevention of weight gain during high-risk periods for weight gain.

Donnelly et al. (7) conducted one of the only randomized, controlled trials to examine physical activity and prevention of weight gain. They randomized overweight college students to either a supervised exercise or a control condition for 16 mo. All exercise was performed under supervision of study staff. Subjects performed 45 min of exercise 5 days/wk. At 16 mo, the average energy expended in the supervised exercise sessions was 3,340 kcal/wk for men and 2,195 kcal/wk for women. There were different effects of exercise in men vs. women. Men in the exercise condition lost weight (~5 kg), whereas control men maintained a constant body weight. Control women gained ~3 kg during the 16 mo, whereas weight gain was completely prevented in women in the exercise condition. These results cannot be used for general recommendations to the public because the first 2 yr of college appear to be a high-risk period for weight gain for women, but not men, and the amount of physical activity required to prevent weight gain then may be greater than for other times in their lives.

How much physical activity is required to prevent weight gain? We lack a strong scientific basis for answering the question of how much physical activity is required to prevent weight gain in the population. There is a lack of prospective, randomized trials that address the question of how much, what type, what intensity, and what duration of physical activity are required to prevent weight gain. Furthermore, the amount of physical activity required to prevent weight gain may differ in different populations and may differ at different times during the lifespan.

We are left with estimating the amount of physical activity required to prevent weight gain. Epidemiological data from DiPietro et al. (6) suggest that a PAL of 1.46–1.60 is required for prevention of weight gain. Given that most people are doing at least low levels of lifestyle physical activity, it may only take an additional 15–30 min of moderate-intensity physical activity for many people to reach this PAL level.

Hill et al. (15) have suggested a theoretical way to estimate the amount of physical activity required to prevent weight gain in a population or subgroup. The degree of energy imbalance can be estimated from weight gain over time. This is done by assuming that each kilogram of body weight gain equals 7,700 kcal and assuming that excess energy is stored with 50% efficiency. Using this strategy, Hill et al. estimated that 90% of the US population is gaining weight due to ≤100 excess kcal/day (i.e., only 10% of the population is gaining weight at a rate greater than could be explained with an extra 100 kcal/day). Increasing physical activity by 100 kcal/day could theoretically prevent weight gain in most of the population (most data suggest there would not be any significant increase in energy intake to compensate for this amount of physical activity). This is comparable to an additional 1–1.5 miles of walking (~15–20 min) or an additional 2,000 steps each day. We estimated the degree of energy imbalance for the general population, but this could be estimated for more defined groups, such as children, college students, or postmenopausal women on the basis of weight gain over time in that group. This could be used to develop behavioral goals (e.g., specific increases in physical activity) to prevent weight gain in that group.

ROLE OF PHYSICAL ACTIVITY IN WEIGHT LOSS

Although it is possible to lose weight with physical activity alone, the amount of physical activity required for substantial weight loss is well beyond what is feasible for most Americans in today's environment. Wing (36) reviewed several studies where physical activity alone was used for weight loss. Although the amount of weight loss with physical activity was significantly greater than zero, it was in the order of only a few pounds.

Similarly, Wing (36) reviewed several studies in which weight loss with diet alone was compared with weight loss

with diet plus exercise. They concluded that most studies found no significant differences in total weight loss but that in just about every study the absolute amount of weight lost was a little higher when diet and exercise were used. This is not surprising given that weight loss is a function of degree of energy imbalance and that a much greater energy imbalance can be created with food restriction than with increased physical activity. Most diets recommend reductions in energy intake of 500–1,000 kcal/day or more. Most obese individuals who are not regular participants in physical activity cannot feasibly produce this much energy imbalance through physical activity alone.

Does losing weight with physical activity increase success in keeping weight off? Even though adding physical activity to food restriction adds little when it comes to initial weight loss, there may be other advantages of engaging in physical activity during weight loss that increase the chances that the weight loss will be maintained. In some, but not all studies, physical activity appears to favorably alter the composition of weight loss so that a higher proportion of weight loss comes from fat and less come from fat-free mass loss (27). Most of the drop in metabolism that occurs with weight loss seems to be due to loss of fat-free mass, so that physical activity during weight loss could result in more fat-free mass and a higher metabolic rate after weight loss compared with the same amount of weight loss without physical activity. This means that total energy expenditure would be higher after weight loss with physical activity vs. food restriction alone, and it could provide an advantage in maintenance of weight loss.

Another advantage of engaging in physical activity during weight loss is that it may better prepare the person to be able to keep weight off. If, as suggested below, large amounts of physical activity are required for weight loss maintenance, it is important that the person be able to engage in this amount of physical activity at the end of the weight loss period. Beginning a physical activity program during weight loss can accomplish this goal.

Additional support for this notion comes from results from the National Weight Control Registry (NWCR) a database of almost 5,000 successful weight loss maintainers. To be eligible for the NWCR, individuals must minimally have maintained a 13.6-kg (30 lbs.) weight loss for at least 1 yr. The average weight loss is about 30 kg maintained for an average of 5.5 yr. Although there is no similarity in the types of diets used to produce weight loss, over 90% of NWCR participants report losing weight with food restriction and physical activity (17).

ROLE OF PHYSICAL ACTIVITY IN MAINTENANCE OF WEIGHT LOSS

In several studies, high levels of physical activity have been found to predict success in long-term weight loss maintenance. Subjects in the NWCR who have succeeded in long-term weight loss maintenance report expending ~2,800 kcal/wk in physical activity (17). More than 90% of the almost 5,000 NWCR participants are maintaining their weight loss with high levels of regular physical activity. The amount of physical activity reported by NWCR participants is positively correlated with the amount of weight they were maintaining. Furthermore a decrease in physical activity in this group is a predictor of weight regain over time (37).

Subjects in the NWCR report engaging in a large variety of activities. Seventy-seven percent of NWCR participants reported walking daily. It is also interesting that a high proportion of NWCR participants report engaging in weight lifting. Twenty-four percent of men and 20% of women report that they regularly lift weight. This is a higher proportion than seen in the general population, especially for women (31).

Schoeller et al. (30) estimated the PAL required to prevent weight regain in subjects who achieved significant weight loss. Schoeller et al. found the risk of weight regain was significantly reduced above a PAL of 1.75. For most weight-reduced individuals, a PAL of greater than 1.75 would be comparable to 80 min/day of moderate-intensity physical activity (brisk walking) or 35 min/day of vigorous activity (jogging). This group later recommended an energy expenditure of 2,500 kcal/wk for weight loss maintenance (33).

Weinsier et al. (34) also examined the amount of physical activity required to prevent weight regain. They also found that a high PAL (1.73) was associated with successful weight maintenance and translated this to be the equivalent of ~80 min/day of moderate activity.

Jakicic et al. (16) found that reduced-obese subjects who engaged in at least 200 min/wk of physical activity were less likely to regain weight than those who engaged in less physical activity.

How much physical activity is required for long-term weight loss maintenance? There is surprising agreement about the amount of physical activity required to maintain a substantial weight loss. It appears that 2,500–2,800 kcal/wk (60–90 min/day of moderate-intensity physical activity) may be required to maintain substantial weight losses (~14 kg or more) (16, 17, 28, 30, 33, 34, 37). In fact, this is the recommendation in the 2005 Dietary Guidelines for maintaining weight loss (5). It is logical that the amount of physical activity required for weight maintenance would increase with greater weight loss, with more physical activity required to maintain higher weight losses.

Does it take more physical activity to prevent weight regain than to prevent weight gain in the first place? There is considerable consensus that most people who are successfully keeping off substantial amounts of weight are engaging in high levels of physical activity. However, the amount of physical activity required to prevent weight gain in the first place may be less. Some have speculated that those who have been obese for long periods of time experienced long-term or permanent metabolic alterations that make it difficult to maintain a substantial weight loss (21). Although the existence of such metabolic changes has not been confirmed, it remains a possibility that very high levels of physical activity may be required in the reduced obese to overcome some metabolic consequence of having been obese. If so, it may take far less physical activity to prevent weight gain than to prevent weight regain after substantial weight reduction.

WHY IS PHYSICAL ACTIVITY CRITICAL FOR WEIGHT LOSS MAINTENANCE?

Although high levels of physical activity appear to be associated with long-term success in maintenance of weight loss, it is not clear why this is the case. Physical activity could be critical for weight loss maintenance just because of its

impact on energy expenditure. As previously mentioned, the body's metabolic rate or total energy expenditure decreases with weight loss. This is due to a drop in resting metabolic rate secondary to a loss of body mass, particularly fat-free mass, and to a drop in the energy cost of weight-bearing physical activity (i.e., it costs less to move a lower body mass). The more that energy expenditure declines with weight loss, the more food intake will have to be lowered in ordered to maintain the weight loss. Any increase in physical activity that occurs with weight loss serves to compensate for the weight loss-induced reduction in total energy expenditure. Theoretically, if physical activity were increased sufficiently to completely compensate for the drop in energy expenditure that accompanies loss of body mass, an individual could maintain a weight loss with a similar amount of energy intake to that consumed before weight loss (14). The additional energy burned in physical activity raises total energy expenditure and may increase it to the point where the food intake required to match energy expenditure is feasible for people to maintain.

Second, increased physical activity could provide an advantage via its effects on body composition. Regular physical activity appears to slightly enhance fat-free mass and, because fat-free mass is metabolically more active than fat mass (18), could enhance resting energy expenditure.

Alternatively, physical activity could be a strong predictor of success in weight loss maintenance because it is a marker for compliance. Those who maintain a high level of physical activity may also be better at maintaining their target energy intake.

Some investigators have reported that fat oxidation is impaired after weight loss (1, 19). Although fat oxidation is positively correlated with amount of body fat (18), Larson et al. (19) found postobese subjects had a lower rate of fat oxidation compared with lean nonreduced controls when consuming a 30% fat diet (food quotient = 0.866) in a respiratory chamber. In this study, the postobese subjects oxidized 27% of fuel mix as fat (respiratory quotient = 0.883), whereas the control group oxidizes 35% of total energy as fat (respiratory quotient = 0.863) A reduction in fat oxidation may be important because it would result in a positive fat balance, making individuals who lose weight more prone to weight gain. Increasing physical activity is a good way to increase total fat oxidation (18) and could partially compensate for any impairment in fat oxidation that occurs with weight loss.

IMPORTANCE OF PHYSICAL ACTIVITY FOR MAINTAINING A HEALTHY BODY WEIGHT

In general, high levels of physical activity may provide an advantage in helping achieving energy balance at a healthy weight. Theoretically, there are many ways to achieve energy balance. For any individual, energy balance can be achieved at different levels of energy intake and expenditure and at different levels of body weight. The fact that more and more Americans are unable to achieve energy balance at a healthy body weight may be directly related to the low levels of physical activity in the population. As PALs decline, total energy expenditure also declines, and the only way to achieve energy balance is by reducing energy intake. This in fact seems to be the strategy used to manage body weight by most people, and it is not working. The average American is gaining 0.45–0.90 kg/yr (15), and this weight gain actually helps achieve energy balance because increased body weight leads to increased total energy expenditure via increased resting metabolic rate and an increased energy cost of moving a larger body (26).

It is likely that physical activity is so low in most people (32) that total energy expenditure has been reduced below the point where it is not feasible to match it with a low level of energy intake. Figure 1 illustrates this concept and is similar to the idea first presented by Mayer et al. (22, 23) that there is a "threshold" of energy expenditure below which it is difficult to precisely match energy intake with energy expenditure. Both our biology (11) and our environment (10, 13) promote eating, and it is difficult to maintain substantial food restriction in the face of these powerful forces. It may be virtually impossible for a large proportion of the population to maintain energy balance at a healthy weight without first increasing physical activity to a point where it can realistically be matched with energy intake. The fact that the majority of the population is above a healthy body weight supports this hypothesis.

This idea that it may be harder to achieve energy balance at low levels of physical activity was originally developed by Mayer and colleagues. They showed in animal models (22) and humans (23) that the greatest likelihood of positive energy balance occurred at the lowest levels of physical activity. Subsequent work has identified potential physiological mechanisms that may be responsive to the level of physical activity. For example, Bell et al. (2) found that resting metabolic rate was higher in individuals achieving energy balance at high vs. low levels of energy intake and expenditure and that this effect was likely mediated by the sympathetic nervous system. Fox et al. (9) found that leptin levels were different in sedentary Pima Indians in Arizona compared with physically active Pima Indians in Mexico.

If this hypothesis is correct, it has important implications for body weight management. It suggests that our population will

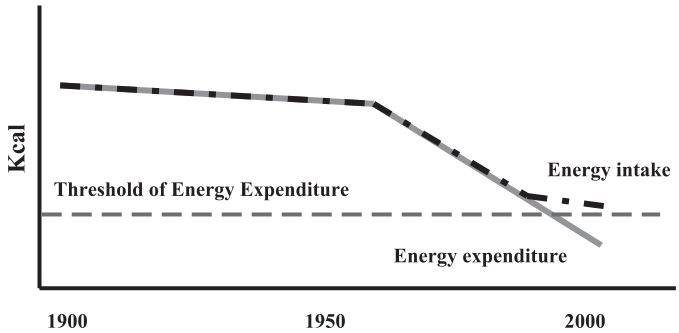

Fig. 1. Hypothetical depiction of how the decline in physical activity over the past decades could have caused total energy expenditure for most people to be reduced below a threshold where it is possible to achieve a balance between energy intake and energy expenditure. Solid line, energy expenditure; dotted line, energy intake. The current obesity-conducive environment in the year 2000 has created a situation where there is the greatest possibility for error in regulating energy balance. The hypothesis is that body weight regulatory mechanisms match intake and expenditure across a wide range of expenditures depicted over the last 100 yr. At very low levels of energy expenditure, however, it becomes difficult for many people to match intake and expenditure, and thus weight gain occurs. Increasing energy expenditure above some level (threshold of energy expenditure) may be necessary to allow for better physiological matching between expenditure and intake and thus allow body weight stability. The figure was developed in collaboration with Dr. Steve Blair, Cooper Institute, Dallas, TX.

never be able to maintain energy balance at a level of healthy body weight without increases in physical activity (see Fig. 1). This also suggests that our current focus on diet and especially diet composition may be misplaced and that there is no diet that will allow us to maintain the low level of energy intake required to achieve energy balance at a healthy body weight, given the current level of physical activity.

HOW TO GET PEOPLE ACTIVE

Although substantial data suggest that increasing physical activity is an important strategy for preventing weight gain and preventing weight regain, we still have a big challenge in producing such increases. The environment we have constructed is not one that encourages physical activity, and in fact many technological advances of the last decades have likely caused substantial declines in physical activity (15). We require very little physical activity for work (or school) or transportation. We increasingly spend our leisure time in front of some sort of glowing screen (i.e., television, video). Even if we agree on the amount of physical activity required for optimum weight management, we have a poor history of success in getting people to permanently become more active.

Increases in physical activity can be promoted in different ways. In general, this can be though promoting planned physical activity or exercise and through promoting increases in lifestyle physical activity. The latter involves showing people how to increase physical activity (i.e., walking) throughout their usual day without the need to set aside planned exercise time. For individuals maintaining a significant weight loss, both strategies will likely be required to achieve sufficient physical activity. For prevention of the 0.45–0.90 kg of weight gained each year by the average American, either strategy alone could be sufficient.

PROVIDING PHYSICAL ACTIVITY RECOMMENDATIONS TO THE PUBLIC

It is important to provide recommendations to the public about physical activity and weight management. One challenge is that these recommendations may differ depending on whether the goal is to prevent weight gain, lose weight, or to prevent weight regain, as described in the previous paragraphs. The previous recommendation to the public of 30 min/day of physical activity was based on data showing that this amount of physical activity has a clear positive impact on cardiovascular health (32). This recommendation is probably not sufficient to prevent weight regain in most of those who are maintaining a large weight loss and may or may not be sufficient to prevent the gradual weight gain seen in most of the population.

The most recent Dietary Guidelines for Americans (5) suggests that 30–60 min are recommended to prevent weight gain. This recommendation reflects the lack of specific information about how much physical activity is required to prevent weight gain, and it provides little guidance for how much is needed for any given person. Some people may think they are getting enough physical activity when they get 30 min/day, and others may see the recommendation of 60 min as too daunting and may not even try to achieve this goal.

For the past several years, physical activity recommendations have been provided to the public in terms of minutes per day. Although this works well with planned physical activity, it may not work as well with lifestyle physical activity. Promotion of lifestyle physical activity involved asking people to engage in more walking during the day and in short bouts of physical activity spread across the day. It is often difficult for people to monitor success of this type of physical activity in minutes.

We must evaluate whether or not promoting physical activity in minutes per day has been successful in getting more people to meet the physical activity recommendations. For example, data from the Centers for Disease Control and Prevention suggest that the proportion of Americans who do not meet recommendations for physical activity has remained relatively constant over the past decade (4).

It may be useful to consider alternative ways to provide physical activity recommendations to the public. Technological advances may be helpful. Some (38) have found that using inexpensive, electronic pedometers and providing physical activity goals in steps per day is effective in increasing physical activity over the short term. It is not yet clear whether this increase is sustainable. As accelerometers and other devices become more inexpensive, these may be useful in helping people increase lifestyle physical activity.

FUTURE RESEARCH DIRECTIONS

Although there is a strong inverse relationship between physical activity and weight gain, there is a great need for prospective randomized trials that show clear cause and effect and allow estimation of how much physical activity is required to achieve weight management goals. There is a need for data to allow quantification of how much physical activity is required to prevent weight gain in those who have never been obese and to prevent further weight gain in those who are already overweight or obese. This value likely varies within subgroups and within individuals. Data are needed to predict the amount of physical activity that would prevent excessive weight gain in children. Obtaining this information is a high priority to provide reasonable and feasible recommendations to the public.

There is a consistent body of data suggesting that 60–90 min of physical activity are associated with increased success in maintenance of weight loss, but no clear understanding of exactly why this is the case. More research is needed to understand why physical activity is so important for those seeking to maintain substantial weight losses.

Finally, there is a need for more research to understand whether there is an optimum amount of physical activity that maximize the changes of achieving energy balance at a healthy body weight and why.

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