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Dieting and weight cycling as risk factors for cardiometabolic diseases: who is really at risk?

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Summary

Despite the poor prognosis of dieting in obesity management, which often results in repeated attempts at weight loss and hence weight cycling, the prevalence of dieting has increased continuously in the past decades in parallel to the steadily increasing prevalence of obesity. However, dieting and weight cycling are not limited to those who are obese or overweight as substantial proportions of the various population groups with normal body weight also attempt to lose weight. These include young and older adults as well as children and adolescents who perceive themselves as too fat (due to media, parental and social pressures), athletes in weight-sensitive competitive sports (i.e. mandatory weight categories, gravitational and aesthetic sports) or among performers for whom a slim image is professionally an advantage. Of particular concern is the emergence of evidence that some of the potentially negative health consequences of repeated dieting and weight cycling are more readily seen in people of normal body weight rather than in those who are overweight or obese. In particular, several metabolic and cardiovascular risk factors associated with weight cycling in normal-weight individuals have been identified from cross-sectional and prospective studies as well as from studies of experimentally induced weight cycling. In addition, findings from studies of experimental weight cycling have reinforced the notion that fluctuations of cardiovascular risk variables (such as blood pressure, heart rate, sympathetic activity, blood glucose, lipids and insulin) with probable repeated overshoots above normal values during periods of weight regain put an additional stress on the cardiovascular system. As the prevalence of diet-induced weight cycling is increasing due to the opposing forces of an 'obesigenic' environment and the media pressure for a slim figure (that even targets children), dieting and weight cycling is likely to become an increasingly serious public health issue.

Keywords: Diabetes, hypertension, obesity, weight cycling.

Introduction

Dieting is a loosely defined lay term with multiple meanings. According to the popular free encyclopedia *Wikipedia* (1), dieting is 'the practice of eating food in a regulated fashion to decrease, maintain, or increase body weight. Dieting is often used in combination with physical exercise to lose weight in those who are overweight or obese. Some people, however, follow a diet to gain weight (usually in the form of muscle)'. The *Oxford Dictionary* (2) provides a definition of dieting that relates specifically to intentional weight loss based not only on food quantity but also food quality, and to quote, 'Restrict oneself to small amounts or special kinds of food in order to lose weight'. Indeed, the term dieting could apply to a wide range of practices and it is common for nutritionists and health professionals to classify dieting methods for weight loss as healthy (e.g. eating less fat and sweets, and more fruits and vegetables) or as 'unhealthy' when the dieting practices involves repeated fasting for lengthy periods, the use of diuretics, diet pills or laxatives, vomiting and smoking (3). In this paper, the term dieting is used synonymously with attempts to lose weight or fat, and refers to weight control behaviours with the intention to lose weight or fat or to be slimmer.

Dieting and weight cycling in different population groups

Prevalence of dieting in the general adult population

In parallel to the increasing prevalence of overweight and obesity, the prevalence of dieting has increased in the last decades, as shown in Table 1. In the U.S. national surveys conducted between 1950 and 1966, about 14% of women and 7% of men reported that they were trying to lose weight (4,5). In the late 1980s, this prevalence had increased to approximately 40% of women and 25% of men trying to lose weight at any given time (6), and during the mid-1990s, in a survey involving over 100,000 adults aged 18 years and older, the prevalence of attempting to lose weight increased further to 44% among women and 29% among men (7,8). By the early years of the New Millennium, the prevalence of trying to lose weight in the United States, assessed from the 2001–2002 *National Health and Nutrition Examination Survey* (NHANES), was found to have increased to 48% among women and 34% among men (9). Currently, based upon the most recent NHANES 2003–2008 survey, three in five U.S. adults desire to weigh less and 57% of women and 40% of men had been on some type of a weight loss diet in the preceding year (10) – which further underscores the trend for increasing prevalence of dieting to lose weight in the United States over the past decade. Similarly in Finland, dieting among young adults has more than doubled during the last decades in parallel to increased obesity prevalence and currently about 50% of the adult population is trying to lose weight (11,12). In France, among the 48,435 adults from the ongoing *Nutrinet-Santé* cohort study, 26% of them (88% women, 12% men) had followed at least one weight loss diet in the previous 3 years (13). Overall, from the relatively few studies on the prevalence of dieting in communities in Europe and North America, it is estimated that currently 25–65% of women and 10–40% of men attempt dieting to lose weight (14,15), with the consistent finding that women are more likely to diet than men. However, individuals who diet to lose weight rarely succeed in maintaining the lost weight in the long term (16–18). Instead, they regain the weight and attempt again. This 'yo-yo' dieting pattern, termed 'weight cycling', refers to this repetitive pattern of weight loss and regain.

Table 1 Prevalence of dieting to lose weight between 1950 and 2010 in the United States

Survey period	Women (%)	Men (%)	Reference
1950–1966	14	7	(4,5)
Late 1980s	40	25	(6)
Mid-1990s	44	29	(7,8)
2001–2002	48	34	(9)
2003–2008	57	40	(10)

Prevalence of weight cycling

Because dieting is so common and the likelihood of regaining the lost weight is so high, weight cycling is assumed to be highly prevalent too (19). However, studies reporting the prevalence of weight cycling in the general population have reported variable results (20–24), with values in the range of 20–35% in men and 20–55% in women. Besides the issue of recruiting different populations, one of the reasons is that there is no universally accepted definition of weight cycling but many possible variations on the same theme (25). As pointed out previously (19), weight fluctuations can be of different lengths or amplitudes (with cut-offs expressed differently as absolute or percentage changes). It is also measured with variable numbers of cycles ranging from one single large cycle to repeated weight cycles in unsuccessful dieters (26) or in athletes who undergo seasonal or even weekly weight losses in order to reach a certain weight category (27). Furthermore, an individual who is observed to be systematically gaining weight at two points in time may be experiencing a number of unmeasured fluctuations in the interim (28), and it is often difficult to distinguish between intentional and unintentional weight loss. Indeed, weight loss after an intention might take place due to the intentional efforts or/and despite of them, and intention might arise after some 'unintentional success' (12,29). Most typically, weight cycling is characterized through subjective questionnaire of intention, duration, frequency and amount of weight losses rather than through objective prospective evaluation. For example, in a U.S. cohort of 46,224 normotensive women of the *Nurses' Health Study II* followed up for 4 years, 78% of the women intentionally lost weight (between 2.25 and 4.45 kg) at least once, 41% had similar weight losses twice or more, and 20.3% reported that they intentionally lost at least 4.5 kg three times within the past 4 years (21). In Finland, an epidemiological study (23) assessing the prevalence of weight cycling in the general adult population found that severe weight cycling, defined as a weight loss of ≥5 kg at least three times followed by some weight regain, was reported by 10% of women and 7% of the men. Mild weight cycling, defined as a weight loss of ≥5 kg once or twice with regain, was reported by 19% of women and 11% of men. Thus, about 29% of women and 18% of men showed some degree of weight cycling. These studies underscore the high prevalence of weight cycling in the general population, particularly among women.

Prevalence of dieting according to weight status

Because the prevalence of attempts to lose weight increases with increasing BMI (6,30,31), it is often assumed that dieting and weight cycling is above all a problem of obese subjects. Indeed, a high prevalence of voluntary weight loss attempts has been reported in overweight and obese subjects in various studies. For example, in a survey of randomly selected subjects 17 years of age and older in Denmark (31), 54% of overweight (body mass index [BMI], from 25 to <30 kg m^{-2}) and 77% of obese people (BMI ≥ 30 kg m^{-2}) reported weight loss attempts at least once in their lives. Furthermore, in the recent nationally representative NHANES 2003–2008 survey in the United States (10), the majority of overweight or obese adults (69% women, 55% men) reported the pursuit of dieting to lose weight during the preceding year. However, it is clear that a history of weight cycling is not limited to overweight and obese subjects, and may also affect lean people of normal weight, and even underweight subjects, including younger subjects (8–10,31,32). In adult Danes, 25% of underweight (BMI < 18.5 kg m^{-2}) and 38% of normal-weight subjects (BMI > 18.5 and <25 kg m^{-2}) reported at least one weight loss attempt in their lives (31). In France, dieters from the ongoing *Nutrinet-Santé* cohort study who had followed at least one weight loss diet in the previous 3 years, 33% of the men and 57% of women were of normal BMI (13). Similarly in Switzerland, among 71% of a sample of 1,053 women in the general population of Geneva who wanted to be thinner, more than two-thirds were at normal body weight (33). Furthermore, an examination of the data from two nationally representative surveys conducted in the United States with an interval of nearly a decade – BRFSS 1996 survey (8) and NHANES 2003–2008 survey (10), indicates that there is a tendency for an increase in the proportion of normal-weight individuals to pursue dieting behaviour for losing weight (see Table 2). While in mid-1990s, among people trying to lose weight, 37% of women and 11% of men were of normal weight, these values reached 46% in women and 19% in men in the mid-2000s; and in the latter study, 13.5% of women and 0.8% men in the underweight BMI category also desired to lose weight (10).

Table 2 Proportion of normal-weight individuals among those dieting to lose weight between mid-1990s and 2010 in the United States

Survey period	Women (%)	Men (%)	Reference
Mid-1990s	37	11	(7,8)
2003–2008	46	20	(10)

Dieting and overweight perceptions

The NHANES 2003–2008 survey also showed overweight perceptions (disturbance of body image) to be positively associated with the desire to lose weight and pursuit of weight control, independent of measured weight status, particularly among young adults (10). Indeed, despite a low BMI among the university student population, many of these young adults perceive themselves as overweight. In a survey of 16,486 university students in 21 European countries (overall BMI of 20.5 kg m^{-2} in women and 22.0 kg m^{-2} in men), 44% of women and 17% of men were trying to lose weight (34). More recently, in an analysis of database from the *Cross National Student Health Survey* (CNSHS) consisting of 5,900 records of university students from different regional areas of western and eastern Europe (35), around 20% of women with average BMI of 20 kg m^{-2} considered themselves 'a little too fat' or 'too fat', and the percentages increased to 60% for a BMI of 22.5 kg m^{-2}. Male students below BMI of 22.5 were more likely to perceive themselves as 'too thin' in that they are far from ideals of lean or muscular body shape.

That exposure to ideal bodies in the media has negative effects on young women's and men's body images has been demonstrated in controlled studies. For example, studies examining the impact of three types of advertisements featuring either thin models, average-size models or no models on adult women's body-focused anxiety have shown that exposure to thin models resulted in an increased body-focused anxiety among women who internalize the thin ideal in comparison to exposure to average-size models or no models (36,37). Young men's body dissatisfaction and body-focused anxiety are also known to increase when they see images of attractive muscular men. An evaluation of some 15 studies addressing the impact of exposing men to advertisements or commercials featuring idealized male bodies on body dissatisfaction (38) reached the conclusion that young men who are dissatisfied with their bodies are at increased risk for negative self-evaluations when exposed to idealized images, whereas men who are satisfied with their bodies may be protected against negative impacts from seeing such images. For example, the impact of media exposure depends upon men's exercise status (39): while non-exercisers reported greater body-focused negative affect after exposure to images of muscular male models than after neutral images (no model controls), gym users ($n = 58$) showed a tendency for less body-focused negative affect after the model images than after the control images. Overall, many young people who are normal weight or underweight are concerned about their body shape and size because of the media and social pressures to conform to a thin body ideal in women or a muscular low fat body ideal in men, often putting them at risk for dieting, weight cycling and engaging themselves in unhealthy weight control behaviours.

Dieting in children, teenagers and adolescents

Because a slim body image is widely promoted by the media and society, trying to lose weight has spread to children and adolescents in an attempt to conform to cultures that advocate '*slim is beautiful*' (40). In a survey of 5th- through 12th-grade girls ($n = 548$) in a working-class suburb in the northeastern United States, 47% of the girls reported wanting to lose weight because of fashion magazine pictures (41). In a cross-sectional mailed survey of 11,606 boys and girls aged 9–16 years, 46% of the girls and 27% of the boys reported making at least some effort to look like figures in the media (42).

Young adolescents, in particular, have a tendency to misperceive their weight status (43), and body dissatisfaction continues to be highly prevalent among girls (24–46%) and boys (12–26%) (44,45) and is increasing worldwide (46,47). In a nationally representative samples of adolescents from over 30 countries in Europe and North America participating in the *Health and Behaviour in School-aged Children* 2001/2002 survey, self-perception of overweight was found to be a more important factor leading to attempts to lose weight in the preceding 12 months than was weight status, age or country of residence (47). Subsequent extension of this international study to 43 countries in Europe and North America indicated that at 15 years of age, 40% of girls and 22% of boys were dissatisfied with their bodies (48). Although there may be inter-country variation in cultural-specific body ideals, the recent report about 9-year trends and relationships regarding misperceptions of body size and dieting for weight loss among adolescent girls and boys from 24 countries concluded that there is no clear geographical patterns with body dissatisfaction and attempts for dieting for weight loss (49).

Adolescents with body dissatisfaction are more likely to take active steps to lose weight, including dieting or use of more extreme methods to change their body weight and shape that can lead to adverse physical and psychological consequences (50). It is estimated that as many as one-third to half of U.S. girls report experimenting with or regularly engaging in unhealthy weight control methods such as fasting, vomiting or laxative use (51). In a study population of 4,746 adolescents from U.S. public schools, 57% of the adolescent girls and 33% of the adolescent boys reported unhealthy practices and 12% of the adolescent girls and 5% of the adolescent boys reported extreme practices (52). Although overweight adolescents report more frequent dieting and use of weight control behaviours than normal-weight adolescents, a substantial proportion of normal-weight adolescent (34% girls and 8% of boys) were currently trying to lose weight (52).

Body dissatisfaction may also affect pre-adolescents and very young children. Girls from age 5 to age 8 exposed to images of the thin Barbie doll reported lower body esteem and greater desire for a thinner body shape than girls exposed to the larger Emme doll or to no doll, which could contribute to an increased risk of disordered eating and later weight cycling (53). In the United States, girls as young as 5 years are aware of dieting practices (54) and they report the desire to lose weight by age 9 years (55), i.e. before adolescence. It is estimated that about 40% of pre-adolescent school-aged girls children have attempted to diet to lose weight (56).

Multiple factors that have been found to impact the onset of dieting in childhood and adolescence, including the stigmatization of obesity which appears to be on the increase (57,58) and the influence of media, peer and parent (59) in driving the socially endorsed ideal of thinness as a beautiful body. In a recent study (60) investigating the association between maternal and paternal encouragement to diet and their daughters' self-reported 'early dieting' (prior to age 11 years), assessed when daughters were 9, 11, 13 and 15 years, both maternal and paternal encouragement to diet were significant independent predictors of early dieting, and remained significant after controlling for daughters' BMI percentile. Compared with girls whose mothers or fathers did not encourage dieting, girls who were encouraged to diet were twice as likely to diet by 11 years, while girls who were encouraged to diet by both parents were eight times more likely to report early dieting than girls who were not.

Dieting in older people

Preoccupation with body weight leading to frequent dieting and weight cycling remain high in older women (61). Indeed, in the 2003–2008 NHANES survey conducted in the United States, the prevalence of older people (>55 years) desired to weigh less was almost as high in younger people (<55 years), namely 70% vs. 75% among women and 59% vs. 54% among men (10). The social pressure to be thin already observed in young women also exists in middle-aged and older women, leading to chronic dissatisfaction with weight in women across the lifespan. This 'normative discontent' (62) – that women seem to accept disliking their body as part of everyday life – and the wish to be thinner drive normal-weight women to engage in dieting even at an older age. For example, even though two-thirds of the women over 65 years of age were at a healthy weight in a sample of 1,053 Swiss women from the general population of Geneva, 62% expressed a desire to lose weight and one-third of these older women had dieted to lose weight with the last 5 years (33). However, in view of their vulnerability to nutritional deficiencies and to loss of muscle and fat-free mass (including bone), dieting behaviour may represent a health threat (63,64). Furthermore, because dieting results in yoyo dieting, and that older people have difficulties in recovering fat-free mass but not fat mass, there is also an increased risk for relative sarcopenic obesity (gain in body fat but loss of muscle and bone mass and functional capacity).

Dieting in entertainment and sports

Slimming is common among performers, such as ballerina dancers, top models, entertainers and pom-pom girls, for whom a slim image is professionally an advantage (41,65,66). Marked intentional weight losses are not rare among movie actors and actresses to fit a specific character in a movie, such as Mathew McConaughey playing a sick AIDS patient in 2013's *Dallas Buyer's Club*, or Tom Hanks stranded in a desert island in 2000's *Cast Away*. Marked weight gain to fit a role is equally common, such as Russel Crowe in 2008's *Body of Lies* or Charlize Theron portraying a real-life serial killer in 2003's *Monster*. It is not rare for an actor to alternate from one extreme to the other, such as Jared Leto gaining weight to play John Lennon's killer in 2007's *Chapter 27*, and then dropping to a dangerously low body weight for his Oscar-winning role as a transgender with AIDS, in 2013's *Dallas Buyer's Club*.

Slimming is also common among athletes involved in certain specific sports (67). Whereas some athletes have the genetic constitution that is tailored to the specific anthropometric demands of the sport and weight category in which they compete, many elite athletes struggle as they attempt to conform to competition regulations that are ill-suited to their physique (68) and indulge in extreme dieting to achieve their weight target or thin body shape prior to the competition – and may include fasting, dehydration (e.g. saunas, exercise with sweat suits), purging such as use of laxatives, diuretics, vomiting, diet pills with or without excessive training. This is of particular relevance to elite athletes competing in the so-called *weight-sensitive sports* (69), namely:

1. The *gravitational sports* – such as ski jumping and other jumping events, endurance sports like long-distance running, cross-country skiing, mountain bike cycling – where excess body weight is associated with a competitive disadvantage since a higher body weight restricts performance because moving the body against gravity is an essential part of these sports;
2. The '*aesthetic*' *sports* – such as figure skating, artistic and rhythmic gymnastics, diving – where athletes are evaluated on technical and artistic forms and where it is believed by many athletes and their coaches that an appearance of 'thinness' is considered by some judges to be an important factor in deciding excellence; and
3. The *sports with mandatory weight categories* – such as weightlifting, rowing and combat sports (wrestling, boxing, martial arts) – where athletes are categorized according to their body weight so that the matches among competitors are more equitable in terms of body size, strength, leverage and agility. In practice, however, many of the athletes in this category reduce body weight before the competition in an attempt to gain some advantage by competing in a category below their habitual training body weight, and hence against lighter, smaller and weaker opponents. Rapid weight loss prior to competition – also known as 'weight cutting' – in weight-categories sports is viewed as an essential part of the sport by the athlete, the coach, the teammates and the organizers (69).

Overall therefore, a low body mass and/or low body fat content is considered to be important for performance and excellence in many sports. Studies documenting physiological profiles of athletes have reported body fat percentage values that are two to three times lower than for the general population of healthy young normal-weight individuals, namely ~5% in male body builders, wrestlers and judo athletes (70–73); 14% on average in elite female gymnasts and runners (74); ~12% in subgroups of middle-distance runners and artistic gymnasts (74); and 10% or less in elite female runners (75). But as it is well recognized, dissatisfaction with either body weight or shape, together with extreme dieting behaviour, is a high-risk factor for the development of eating disorders, including in athletes (76–80). Because competitive sports activity may start at a young age, it is not surprising to observe weight cycling in adolescent athletes too (81–83).

Dieting, weight cycling and long-term adverse health consequences

As documented earlier, the prevalence of repeated dieting to lose weight and weight cycling is high in the general population and is not restricted to obese and overweight persons. It is substantial even among lean (non-overweight) population subgroups that include people with overweight perception, performers and entertainers, and athletes in weight-sensitive sports (Fig. 1). There are concerns about long-term adverse health consequences, and over the past decades, dieting and weight cycling have been implicated in increased risk for eating disorders and other psychological

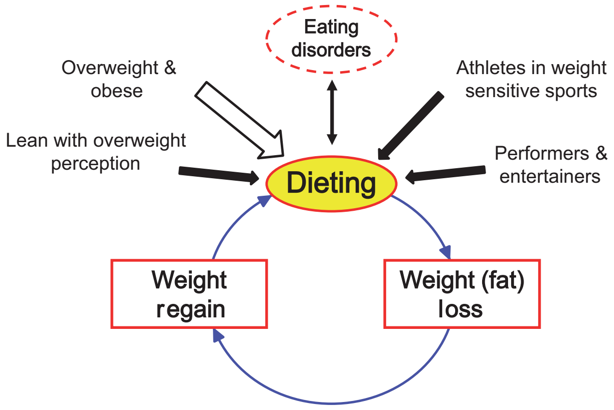

Figure 1 Typical population groups that use dieting to lose weight and are at risk for weight cycling.

disorders (such as increased anxiety and depression), in a variety of increased morbidities that includes obesity, type 2 diabetes, hypertension, cancer and bone fracture, and increased general mortality. However, the topic of health consequences of weight cycling has been the source of considerable controversy (25,28,84), with ongoing debates about whether it is prudent to even recommend that overweight or obese adults should try to lose weight (85).

The debate has been particularly vivid concerning the associations between weight cycling and type 2 diabetes, cardiovascular morbidity and all-cause mortality. Indeed, although most of the early epidemiological studies suggested that weight fluctuations or weight cycling were associated with an increased risk of cardiometabolic morbidity or mortality (86–89), the findings from the subsequent studies have not been consistent (90–100). For example, in the 6-year follow-up of young and middle-aged female nurses from the *Nurses' Health Study II* (93), as well as in middle-aged men and women in a subset of the *Framingham Heart Study* (97), the association between weight cycling and higher rates of type 2 diabetes was no longer significant after adjustment for overall weight status, suggesting that weight cycling was not independently predictive of developing type 2 diabetes. These findings contrast with that of a more recently reported 9-year prospective study (98) in Finnish men smokers aged 50–69 years in whom large weight fluctuation increased the risk of type 2 diabetes both in men who gained weight (> or = 4 kg), had stable weight (+/– <4 kg) and lost weight (> or = 4 kg) compared to those with stable weight and moderate fluctuation, suggesting that large weight fluctuation is an independent risk factor for type 2 diabetes. Similarly, although several large population-based prospective studies have reported an increased risk for all-cause and cardiovascular mortality in association with weight cycling even after adjusting for pre-existing disease (86,88–92,94,95), a number of more recent large-scale studies have failed to confirm the association between weight cycling and cardiovascular mortality (96,99,100).

These discrepancies could be attributed, as discussed previously, to differences in population groups under study and methods used for their assessment. In the absence of a consensus for a standard definition of weight cycling or weight fluctuation, it is difficult to make cross-study comparisons, thereby leading to challenges in drawing definitive conclusions (101). Nonetheless, an analysis of data of the literature suggests that it is weight cycling resulting from repetitive intentional weight loss in the young and primarily normal-weight population groups that seems to be more strongly associated with risks for metabolic and cardiovascular diseases, as elaborated in the following section.

Potential cardiometabolic risk factors promoted by weight cycling

It should first be underlined that in the analysis of the 32-year follow-up data of participants in the *Framingham Heart Study* (88), the strongest and most consistent associations between weight fluctuation and morbidity and mortality from coronary heart disease were observed in the youngest cohort of men and women, thereby suggesting that weight fluctuation in early adulthood may have different cardiovascular implications from subsequent weight changes. Since then, several metabolic and cardiovascular risk factors associated with weight cycling in primarily young and normal-weight population groups have been identified from a number of cross-sectional and prospective studies as well as from studies of experimentally induced weight cycling; these are described below.

Enhanced weight gain

A larger weight gain associated with dieting and weight cycling in population groups that are primarily of normal body weight has been reported in Japanese men (102), in elite Finnish athletes who practised power sports (103) and in several prospective studies in adolescents growing into adulthood or in young adults of the general population in Europe and North America (32,104–108). Of particular interest is the 6- to 15-year follow-up cohort study in Finland (32) reporting that initially normal-weight subjects who were attempting to lose weight had twice the risk of major weight gain (>10 kg) than non-dieters. In contrast, the history of weight loss attempts in initially overweight male and female subjects in the latter cohort was not consistently associated with increased risk of major weight gain, thereby suggesting that the long-term impact of dieting on susceptibility to fatness may be greater in the lean than in those who are overweight or obese. Further evidence that weight cycling among those who are lean is a robust predictor of future weight gain can also be derived from the recent analysis of a large population-based cohort of mostly normal-weight adolescents ($n = 4,129$) with a follow-up from adolescence to young adulthood (108). This study not only revealed a dose-dependent association between the number of lifetime intentional weight losses (i.e. the frequency of weight cycling), gain in BMI and risk of overweight, but also showed that the rate of weight gain was higher among those who were in the lowest baseline BMI category than those in the intermediate or higher baseline BMI category. Explanations as to why those with normal BMI seem more predisposed to future weight gain than overweight or obese subjects are discussed in a companion review article by Dulloo *et al.* (109). Taken together, these observations are of major public health interest, as weight gain is well known to be an independent risk factor for the development of type 2 diabetes (110), hypertension (111) and coronary heart disease (112).

Hyperinsulinaemia and insulin resistance

A direct association between weight cycling and fasting hyperinsulinaemia has also been demonstrated in Japanese subjects (113). In this cross-sectional analysis of 1,932 middle-aged Japanese men with an average BMI of 22.7 kg m^{-2}, a positive association was found between fasting insulin concentration and a history of weight fluctuations in the preceding ~30 years. Individuals with larger weight fluctuations had significantly higher fasting insulin, independently of BMI and other confounding variables. When the participants were categorized accordingly into two groups (i.e. normal weight with a BMI < 25 kg m^{-2} and overweight with a BMI ≥ 25 kg m^{-2}), this association remained statistically significant only in the normal-weight subgroup ($P = 0.002$) but not in the overweight subgroup. In another study investigating the relationship between weight cycling and the metabolic syndrome in 664 middle-aged Japanese men, a positive correlation between high fasting glucose and a history of weight cycling could only be shown to be statistically significant in the group of men with a BMI < 25 kg m^{-2} (102). In a more recent study of experimentally induced weight cycling in 10 young German men of normal BMI (23 kg m^{-2}) subjected to one cycle of controlled 7-day period of caloric restriction and 7-day period of refeeding, fasting and postprandial insulin sensitivity was found to be impaired at the end of the refeeding period when body weight and body fat were not different relative to the baseline values (114). Taken together, these observations suggest that weight cycling may promote insulin resistance in normal-weight subjects.

Dyslipidemia and hypertension

Alterations in blood lipids have also been reported in a cross-sectional study exploring the association of long-term body weight fluctuations with components of the metabolic syndrome in middle-aged Japanese men (102). Hypertriglyceridemia and low high-density lipoprotein-cholesterol (HDL-c), but also hypertension and insulin resistance, were significantly associated with higher body weight variability, a significance that was evident in the group of men with BMI < 25 kg m^{-2}, whereas significance was lost in the group of men with BMI ≥ 25 kg m^{-2}. More recently, in a 7-year follow-up French national cohort study of 3,553 middle-aged subjects (mean BMI < 25), weight cycling was shown to be an independent risk factor for metabolic syndrome (an increased risk for blood pressure [BP], HDL-c and waist circumference), independent of the relative weight change and other confounding variables (115). Of particular interest in support of a cause–effect relation between weight cycling and components of the metabolic syndrome are the results of a well-controlled experimental trial conducted in five young and lean healthy Japanese women (average BMI 20.5 kg m^{-2}) who underwent two cycles of diet-induced weight loss of about 4.4 kg and *ad libitum* weight regain. Plasma triglycerides and systolic and diastolic BPs were all significantly increased at the end of the study, more than 100 days after the end of the second weight loss period (116). Furthermore, the report in the latter study in lean Japanese women (116) of wide fluctuations in plasma triglycerides and BP during their two experimental weight cycles, together with recent findings of an overshoot of serum insulin at the end of one cycle of caloric restriction in lean German men (114), is in support of the 'repeated overshoot' theory (19) put forward as additional mechanisms linking weight cycling to cardiovascular diseases, as summarized below.

The 'repeated overshoot' theory

According to the theory (19) illustrated in Fig. 2, sustained fluctuations in energy balance as it occurs during weight cycling will lead to potential fluctuations of cardiovascular and renal risk variables, such as BP, heart rate, cardiac workload as estimated by the product of systolic BP and heart rate (117), sympathetic activity, glomerular pressure-induced renal filtration, blood glucose and lipids, with a decrease below normal values during periods of weight loss and an increase above normal values (and thus the term of overshoot) during periods of weight regain; these fluctuations may occur around stable average values or on a background of a baseline drift as it may occur during growth, ageing, weight gain or during the development of cardiometabolic diseases. In turn, the stress induced by repeated overshoot of these risk variables during food excess periods with weight regain may not be compensated by decreases of the same risks factors during weight loss periods. Furthermore, the oscillations are not always symmetric. For example, caloric excess leads to a rapid and

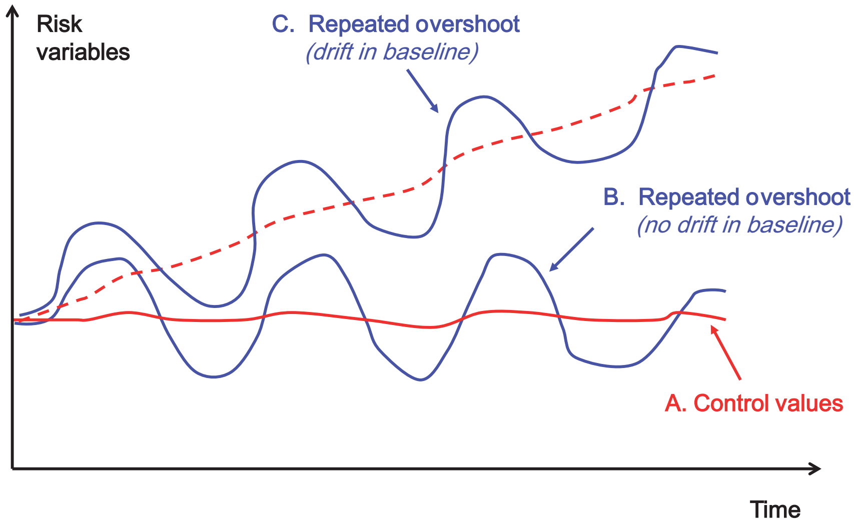

Figure 2 Concept of repeated overshooting. Weight cycling may lead to fluctuations of cardiovascular and renal risk variables, such as BP, heart rate, sympathetic activity, renal filtration, blood glucose and lipids with repeated overshoots (B, C), even if the average values remain stable (A) or on a background of a baseline drift (C).

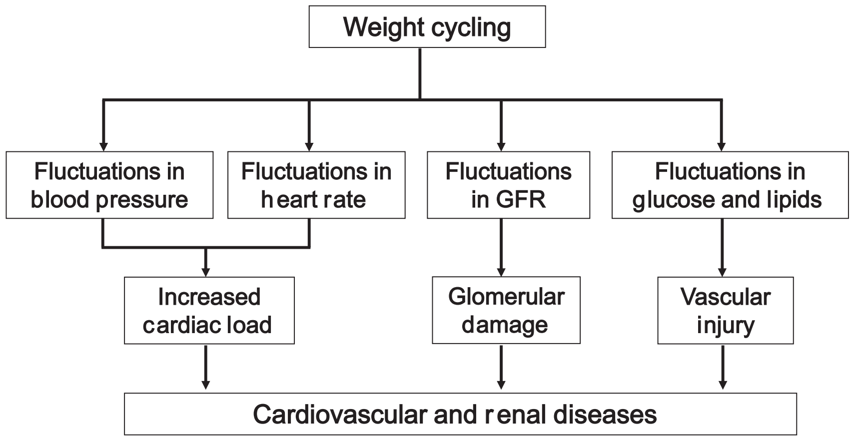

Figure 3 The 'repeated overshoot' theory (19): Repeated overshoot of some cardiovascular and renal risks factors during the weight regain phase of weight cycling may contribute to overall morbidity and mortality even when the average values are normal. GFR, glomerular filtration rate.

sustained tachycardia, whereas caloric restriction leads to a progressive bradycardia over several days, as shown in rabbits (118).

As a consequence, the fluctuations of cardiovascular and renal risk variables, such as BP, heart rate, sympathetic activity, renal filtration, blood glucose and lipids, put an extra load on the heart and may lead to glomerular damage and vascular injury, as illustrated in Fig. 3. Fluctuations of these risk parameters may be overlooked if the subjects are studied in a situation of relatively stable weight; the fluctuations will also add a background noise in the statistical analysis if the subjects are observed in cross-sectional studies with a single snapshot in a history of weight cycling, obscuring the true fluctuations of risk variables during weight cycling (19). Yet, fluctuations of several cardiovascular risk parameters do occur during fluctuations in food intake. Higher than normal values of BP, heart rate, sympathetic activity, glucose, insulin, triglycerides and cholesterol, as well as glomerular hyperfiltration, have all been described during rapid weight gain after a period of food restriction (see Ref. (19) for details).

Conclusions

Dieting and weight cycling are not limited to those who are obese or overweight as substantial proportions of the various population sub-groups considered to be within the normal range of a healthy body weight also attempt to lose weight. This include young and older adults as well as children and adolescents who perceive themselves as too fat (often due to media, parental and socio-cultural pressures), elite athletes in weight-sensitive sports or among performers for whom a slim image is professionally an advantage. Of particular concern is the emergence of evidence that some of cardiovascular risk variables of dieting and weight cycling are more readily seen in people of normal weight rather than in those who are overweight or obese. In addition, fluctuations of cardiovascular risk variables, such as BP, heart rate, sympathetic activity, blood glucose and lipids, with probable repeated overshoots above normal values during periods of weight regain, may put an additional stress on the cardiovascular system. As the onset of a pattern of weight cycling is shifting towards younger ages and since cardiovascular risk factors, even when only moderately present, act together in multiplicative way to lead slowly over many years to cardiovascular events, an increase in the prevalence of cardiovascular and renal diseases associated with weight cycling is expected in the next few decades.

Conflict of interest statement

All authors declare no conflict of interest.

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