Psychologic and Physiologic Effects of Dieting in Adolescents

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ABSTRACT: Obesity in adolescents has increased by 75% in the past three decades. Cross-sectional and prospective surveys have shown that a large percentage of adolescents, particularly females and even those of normal weight, diet at some time. While moderate changes in diet and exercise have been shown to be safe, significant psychologic and physiologic consequences may occur with extreme or unhealthy dieting practices. Moderate dieting has been shown to be associated with negative self-esteem in some adolescents. The very act of starting any diet increases the risk of eating disorders in adolescent girls. Extreme methods of weight loss can have adverse physiologic effects if not closely monitored. Electrolyte disturbances, cardiac dysrhythmias, and even sudden cardiac death can result from unhealthy or extreme dieting practices. Such practices are associated with other problem behavior in adolescents. We review current information on dieting in teenagers and discuss psychologic and physiologic effects of these practices.

Adolescents, especially females, are bombarded with messages from the media about thinness, images of so-called beauty, and ways to achieve a lower body weight. These images, combined with a society that places a high value on physical beauty, send mixed messages to teenagers and may result in unhealthy, frequently unnecessary, attempts to lose weight.

Dieting has become increasingly widespread, not only to achieve current ideals of thinness, but also because of the increased prevalence of adolescent obesity (an increase of 75% in the past three decades). Approximately 16% of adolescents are mildly overweight with body mass index (BMI) in the 85th to 95th percentile, while 9.9% of adolescents are severely overweight (BMI ≥95th percentile). Being overweight as an adolescent (BMI >75th percentile) is a significant predictor of increased risk for later atherosclerotic coronary artery disease, colorectal cancer, gout, and arthritis. Being overweight as an adolescent may be a greater risk factor for these conditions than being overweight as an adult. Additionally, obese adolescents have a 70% chance of being obese adults, and obesity in adulthood is associated with several disease states, including obstructive sleep apnea, hypertension, adverse lipoprotein profiles, diabetes mellitus, coronary heart disease, stroke, colorectal cancer, and death from all causes. Aside from its association with various medical conditions and disease states, obesity is also associated with fewer years of education, increased poverty, and a lower marriage rate.

Given its prevalence, there is an obvious need for attention to obesity, preferably starting at an early age, in an effort to prevent such problems. The answer does not lie in the current trend of attempts to attain quick

KEY POINTS

- Approximately 16% of adolescents are mildly overweight, while 9.9% are severely overweight.
- Of dieting adolescents, 1% to 8.9% report using potentially dangerous methods of weight loss.
- Potential causes for morbidity and mortality related to dieting practices include a direct toxic effect of the diet, starvation-induced myocardial atrophy, imbalances of electrolytes, and preexisting repolarization defects.
- Given the potential consequences of dieting, obesity prevention should be the primary intervention point.
- When weight loss is necessary, the most appropriate method remains modest caloric restriction, consisting of a balanced macronutrient and micronutrient intake combined with increased physical activity.
fixes using unhealthy dieting practices, including those that promise rapid weight loss over short periods of time.

Because dieting is commonplace among adolescents, health care practitioners should be aware of its potential adverse effects, both psychologic and physiologic. Concerns about dieting include its possible association with cycles of weight loss and re-gain that increase the likelihood of developing eating disorders and obesity; decreased self-esteem and other psychologic issues; and potential increases in cardiovascular risk factors and mortality, both long-term and acute. The potentially devastating outcome of dieting practices is tragically illustrated by the case report elsewhere in this issue, outlining the sudden death of a 16-year-old girl who was attempting to follow a high-fat, high-protein, low-carbohydrate diet regimen.6 In this paper, we assess the current dieting practices among adolescents and review the potential adverse physiologic and psychosocial consequences associated with dieting during adolescence.

### THE PREVALENCE OF DIETING

The Centers for Disease Control and Prevention (CDC) monitors 6 categories of health risks in adolescents, including unhealthy dietary behavior, with the Youth Risk Behavior Surveillance (YRBS) system.7 Several studies have used the YRBS or a similar tool to assess current dieting practices among various populations of adolescents. Current data show that significantly more female adolescents practice weight-control behavior than their male counterparts. Storz and Greene7 reported that 169 adolescent girls (83%) in their study wanted to lose weight, despite the fact that 104 (62%) of them were within the normal range for body weight. An overwhelming majority of the girls reflected a suboptimal body concept, used more negative than positive adjectives to describe their appearance, and chose ideal figure outlines that were smaller than their actual figures. In a study of Taiwanese female college students, only 16.2% were actually overweight or obese, yet 51.4% perceived themselves as such.8

A high percentage of the subjects practiced dieting and/or exercise to lose weight, regardless of their actual body weight. The prevalence estimates from several studies of weight-loss and/or weight-control efforts by adolescents are summarized in Table 1.

Dieting can include a wide range of behavior; therefore, it is important to determine not only the prevalence of dieting among adolescents, but also to specify the types of weight-loss methods that are used (Table 2). In many cases, dieting is inappropriate, in that normal-weight adolescents are frequently the ones that are using dieting and other weight-loss methods. A minority (10% to 27%) report the use of unhealthy, and possibly dangerous, weight-loss methods such as skipping meals, use of very-low-calorie diets, eating only 1 food per day, or use of powdered diet drinks (Table 2). A more alarming figure was the percentage (1% to 8.9%) using dangerous weight-loss methods, including fasting, self-induced vomiting, laxatives, or diet pills (Table 2).

Different interpretations of the term dieting may cause variation in the prevalence estimates of weight-loss behavior among adolescents. Some define dieting as simply watching what they eat, while those at the other extreme define dieting as using drastic measures such as fasting,

### Table 1. Prevalence of Weight-Loss or Weight-Control Attempts in Adolescents

<table>
<thead>
<tr>
<th>Study Question</th>
<th>Sample</th>
<th>No. of Subjects</th>
<th>Yes (%)</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trying to lose weight in the past 30 days</td>
<td>9th-12th grade students</td>
<td>15,349</td>
<td>59.4</td>
<td>26.1</td>
<td>42.7</td>
<td></td>
</tr>
<tr>
<td>Actively attempting to lose or control weight in the past 7 days</td>
<td>9th-12th grade students</td>
<td>16,125</td>
<td>57.6</td>
<td>24.9</td>
<td>41.5</td>
<td></td>
</tr>
<tr>
<td>Trying to lose weight in the past year</td>
<td>9th-12th grade females</td>
<td>1,015</td>
<td>41.4</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Trying to lose weight</td>
<td>9th-12th grade students</td>
<td>3,055</td>
<td>61.6</td>
<td>21.5</td>
<td>41.1</td>
<td></td>
</tr>
<tr>
<td>Trying to lose weight</td>
<td>6th-8th grade students</td>
<td>2,331</td>
<td>50.6</td>
<td>30.5</td>
<td>40.5</td>
<td></td>
</tr>
<tr>
<td>Trying to maintain weight</td>
<td>6th grade females</td>
<td>206</td>
<td>22.2</td>
<td>23.1</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>Wanted to lose weight</td>
<td>6th grade females</td>
<td>206</td>
<td>58.0</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ever dieted</td>
<td>6th grade females</td>
<td>206</td>
<td>53.0</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Currently trying to lose weight</td>
<td>10th grade females</td>
<td>341</td>
<td>53.7</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Ever been on a diet</td>
<td>5th-12th grade students</td>
<td>6,728</td>
<td>45.4</td>
<td>20.2</td>
<td>32.5</td>
<td></td>
</tr>
<tr>
<td>Subgroups:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5th-8th grade students</td>
<td></td>
<td>35.6</td>
<td>18.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9th-12th grade students</td>
<td></td>
<td>56.3</td>
<td>22.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
vomiting, or diet pills. This distinction often is not accounted for in research. In a study evaluating the gradations of adolescent weight-control behavior, 44% of adolescent females reported trying to lose weight on the previous day, yet only 8.6% of the food records reflected dieting.\(^8\) This discrepancy was accounted for by adolescents’ misinterpretation of dieting to mean just watching what they ate. This variation among adolescents in interpretation of dieting must be considered when reviewing the literature on adolescent weight-loss behavior.

### TABLE 2. Prevalence of Specific Weight-loss Methods

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>No. of Subjects</th>
<th>Yes (%)</th>
<th>Females</th>
<th>Males</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDC,(^1) 2000</td>
<td>9th-12th grade students</td>
<td>15,349</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decreased caloric intake</td>
<td></td>
<td></td>
<td>56.1</td>
<td>25.0</td>
<td>40.4</td>
<td></td>
</tr>
<tr>
<td>Exercise</td>
<td></td>
<td></td>
<td>67.4</td>
<td>49.5</td>
<td>58.4</td>
<td></td>
</tr>
<tr>
<td>Fasting</td>
<td></td>
<td></td>
<td>18.8</td>
<td>6.4</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>Diet pills, powders, or liquids</td>
<td></td>
<td></td>
<td>10.9</td>
<td>4.4</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>Vomiting and/ or laxatives</td>
<td></td>
<td></td>
<td>7.5</td>
<td>2.2</td>
<td>4.8</td>
<td></td>
</tr>
<tr>
<td>Story et al,(^4) 1998</td>
<td>9th-12th grade students</td>
<td>16,125</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate weight-control methods (all methods except vomiting or diet pills)</td>
<td></td>
<td></td>
<td>52.1</td>
<td>23.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme weight-control methods (vomiting and/or diet pill use)</td>
<td></td>
<td></td>
<td>5.5</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>French et al,(^3) 1995</td>
<td>9th-12th grade females</td>
<td>1,015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthy weight-loss methods(^a)</td>
<td></td>
<td></td>
<td>21.5</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Both healthy and unhealthy methods(^\dagger)</td>
<td></td>
<td></td>
<td>15.2</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Vomiting</td>
<td></td>
<td></td>
<td>4.4</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Diet pills</td>
<td></td>
<td></td>
<td>5.4</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Appetite suppressants</td>
<td></td>
<td></td>
<td>3.3</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Laxatives</td>
<td></td>
<td></td>
<td>1.6</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Diuretics</td>
<td></td>
<td></td>
<td>1.0</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Krowchuk et al,(^9) 1998</td>
<td>6th-8th grade students</td>
<td>2,324</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exercise</td>
<td></td>
<td></td>
<td>71.0</td>
<td>48.0</td>
<td>59.4</td>
<td></td>
</tr>
<tr>
<td>Dieting</td>
<td></td>
<td></td>
<td>44.9</td>
<td>24.4</td>
<td>34.5</td>
<td></td>
</tr>
<tr>
<td>Vomiting/Laxatives</td>
<td></td>
<td></td>
<td>9.7</td>
<td>4.0</td>
<td>6.8</td>
<td></td>
</tr>
<tr>
<td>Diet pills</td>
<td></td>
<td></td>
<td>8.8</td>
<td>4.7</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>Neumark-Szatainer et al,(^10) 1995</td>
<td>10th grade females</td>
<td>341</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate weight-loss methods(^**)</td>
<td></td>
<td></td>
<td>17.9</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Unhealthy methods(^\dagger)</td>
<td></td>
<td></td>
<td>27.9</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Dangerous methods(^\ddagger)</td>
<td></td>
<td></td>
<td>7.9</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Patton,(^11) 1999</td>
<td>9th-12th grade students</td>
<td>1,685</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate dieters</td>
<td></td>
<td></td>
<td>60.0</td>
<td>29.0</td>
<td>45.0</td>
<td></td>
</tr>
<tr>
<td>Severe dieters</td>
<td></td>
<td></td>
<td>8.0</td>
<td>0.5</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Neumark-Szatainer et al,(^12) 2000</td>
<td>5th-12th grade students</td>
<td>6,728</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ever binge-purge cycling</td>
<td></td>
<td></td>
<td>13.4</td>
<td>7.1</td>
<td>10.2</td>
<td></td>
</tr>
<tr>
<td>Binge-purge behavior</td>
<td>at least once per day</td>
<td></td>
<td>8.9</td>
<td>4.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Healthy weight loss methods were defined as calorie reduction, increased exercise, increased fruit and vegetable intake, eliminating snacks, decreasing fat intake, eliminating sweets, reducing the amount of food consumed, changing the type of food eaten, eating less meat, eating less high carbohydrate food, and eating low-calorie foods.

\(^\dagger\)Unhealthy weight loss methods were defined as fasting, skipping meals, smoking, laxative use, diuretic use, appetite suppressant use, diet pill use, and vomiting.

\(^**\)Moderate weight loss methods were defined as exercise, balanced diet inclusive of food groups, behavior modification, eating less fats and sugar, consultation with a health care professional, and participation in a weight loss group.

\(^\dagger\)Unhealthy methods were defined as skipping meals, use of very-low-calorie diet, eating one food a day, and use of powdered diet drinks.

\(^\ddagger\)Dangerous methods were defined as fasting, vomiting, use of laxatives, and use of diet pills.

**POSITIVE CONSEQUENCES OF DIETING**

Despite potential dire outcomes with improper use, positive health consequences are associated with moderate dieting behavior in adolescents. Moderate dieters, those using all dieting methods except vomiting, diet pills, and extreme calorie-restriction, reported more health-promoting behavior than their nondietering and extreme-dieting (those vomiting or using diet pills) counterparts.\(^3,10\) Moderate dieters had increased fruit and vegetable intake, lowered fat intake, and increased physical activity when compared with the other 2 groups. Those
trying to lose weight are more likely to decrease servings of high-fat meats and dessert foods and increase days of hard exercise, compared with nondieters.11

Dieting and weight loss in obese teens have several potentially positive health outcomes. Insulin resistance, hyperinsulinemia, and high cholesterol levels decrease with weight reduction in obese adolescents.5,11 Escobar et al19 found that altered hepatic insulin clearance in obese children was reversible with weight loss, resulting in near-normalization of serum insulin levels. In addition to correction of abnormal results of serum chemistry tests and insulin resistance, weight loss in morbidly obese subjects decreases upper-airway obstructive symptoms and improves sleep function.5

Although energy restriction with moderate dieting has been associated with decreased linear growth, the decreased linear growth velocity is temporary and not associated with permanent stunting.20 A multidisciplinary weight-reduction (calorie restriction with moderate exercise) program for obese adolescents showed that the majority of subjects were able to sustain normal growth velocity while effectively decreasing body weight.21

NEGATIVE CONSEQUENCES OF DIETING

Physical Consequences

Negative physical consequences of excessive dieting can include delayed linear growth and delayed puberty.22 In a study evaluating children with short stature and/ or delayed puberty, approximately 7% of the subjects fit a pattern of growth-failure due to malnutrition resulting from self-imposed calorie restriction, arising from a fear of obesity.23 Normal weight gain decreased in these adolescents at 12 years of age, followed by a decline in linear growth velocity. Puberty was also delayed in half of the subjects, and bone age was delayed 0.5 to 5.5 years.

Adolescent weight-loss behavior has been associated with an increased risk of long-term weight gain. A prospective cohort study of high school females found that those who restricted their dietary intake, exercised for weight control, and labeled themselves as dieting were at increased risk for obesity later in life.24 Appetite-suppressant and laxative use, vomiting, and binge eating also predicted greater weight gain over the 3-year study period. After controlling for initial body mass, adolescents who reported dieting and other weight-loss efforts, either healthy or unhealthy, were more likely than those who did not report these efforts to gain weight.

Dieting in obese adolescents is associated with a decreased resting energy expenditure. A low-energy diet, comprised of calorie restriction only, causes a significant reduction in resting energy expenditure.24-26 The reduction in resting energy expenditure exceeded that accounted for by changes in lean body mass by 15% in one study.25 At a certain point in weight-loss efforts, obese patients have to either further decrease caloric intake or preferably increase physical activity to continue to lose weight. The high rate of failure to lose weight in obese children and adolescents may be attributed to this decreased resting energy expenditure.

Psychosocial Consequences

Dieting can also have a significant impact on psychologic health in adolescents, during a time of rapid physical, psychologic, and social development. Several studies have correlated adolescent problem behavior with dieting status.12,22 The most negative patterns of psychosocial and health behavior were found among frequent dieters and purgers, while the most positive patterns were found among the group of never-dieting nonpurgers.27

Independent of age, BMI, and known smoking predictors, contemplation of cigarette use has been shown to be positively related to weight concerns, and experimentation with cigarettes has been shown to be positively related to engaging in weight-control behavior.26 Each day in the United States, more than 3,000 adolescents become habitual smokers and more than 6,000 try their first cigarette. It is unknown what percentage of these new smokers start, at least in part, as a means of controlling weight; however, nearly 75% of them will become addicted, and the physical consequences of smoking are well documented in the literature. Unhealthy weight-loss methods have been shown to be frequently associated with other problem behavior, such as alcohol or marijuana use, school delinquency, engaging in unprotected sex, and suicide attempts.27 Increased frequency of dieting and purging behavior have been shown to be independently associated with increased health-risk behavior in adolescent females and to a lesser extent in males.28 Compared with nonpurging adolescents, purgers (and frequent dieters, to a lesser extent) were more likely to use alcohol, tobacco, and drugs. Additionally, they performed more poorly in school, were more likely to be sexually active, and more frequently reported physical abuse or sexual abuse than their non-purging counterparts. They were almost three
times as likely as their healthy-dieting peers to score high on measures assessing suicide risk. Both purging status and dieting frequency were correlated with negative body image, emotional and family stress, and lower "connectedness" with family and others. Analysis of self-esteem changes among 60 obese adolescents enrolled in a 12-week multidisciplinary weight-loss program found a significant decrease in self-esteem scores, most notably in the physical attributes and appearance subscales. Despite attempts at dieting using various methods, they had no significant decrease in weight when compared with control subjects. It has been suggested that recruiting obese adolescents into weight-loss programs diminishes their coping mechanisms for maintaining self-esteem.

The biggest concern about dieting practices of adolescents is the relationship between dieting and the subsequent development of eating disorders, including anorexia nervosa, bulimia nervosa, and binge eating. Approximately 1% of teenage girls have anorexia nervosa, 2% to 3% of young women have bulimia, and 3% to 5% more have variants of disordered eating. Several obvious health complications are associated with eating disorders. Complications of anorexia nervosa are usually due to starvation and include amenorrhea, estrogen deficiency, osteopenia, hypophosphatemia, renal dysfunction, anemia, leukopenia, and cardiac abnormalities. Complications of bulimia include hypokalemia and other electrolyte disturbances, with the potential for cardiac arrhythmias, menstrual irregularities, gastric dilation and rupture, esophageal rupture, Mallory-Weiss tears with upper gastrointestinal bleeding, parotid gland enlargement, tooth erosion, and esophagitis.

Binge eating has been associated with frequent dieting and purging in adolescents. Girls and boys who reported dieting frequently (more than 5 times in the past year) were almost twice as likely to have fears of being unable to stop eating and to binge eat. Purging adolescents were approximately 3 times as likely to binge eat or fear being unable to stop eating. A study of adolescent females found that binge eating was prevalent among dieters using unhealthy or dangerous weight-control methods and those with a high-risk psychologic profile. The researchers suggested that dieting is probably not appropriate for those with poor self-perception because of the subsequent increased risk for eating disorders.

In a population-based cohort study for predictors of eating-disorder onset in adolescents, fewer than 1-in-500 nondieter female subjects developed an eating disorder over 12 months. Adolescent females dieting at a moderate level were 5 times more likely to develop a new eating disorder within 6 months and had a 1-in-40 chance of developing a new eating disorder over 12 months. At highest risk were female severe dieters. They were 18 times more likely to develop a new eating disorder within 6 months than those who did not diet and had almost a 1-in-5 chance of developing a new eating disorder over 12 months. Seventy-four percent of patients with bulimia attributed the development of their eating disorder to the inability to maintain a low-carbohydrate diet, leading to carbohydrate craving and subsequent cycles of binging and purging. Restained eating and dieting practices, independent of body weight, was found to be a better predictor of future eating problems than obesity. These findings are similar to those of Keys et al. Male military volunteers were placed on a very-low-calorie diet. All of them had symptoms of eating disorders, including preoccupation with food, food hoarding, and emotional instability.

Several studies have also suggested an association between psychiatric morbidity or disorders and the development of eating disorders; however, the question still remains whether dieting behavior and eating disorders result in the development of the psychiatric disorder or vice versa. Buddeberg-Fisher et al found that a substantial number of adolescent females had more than one psychiatric disorder, and that psychiatric morbidity had the strongest correlation with negative body image. This study raises the concern that psychiatric disorders may be related to dieting behavior among adolescents.

Biochemical and Physiologic Consequences

The primary acute effect of most concern regarding various types of diets and dieting behavior are the anecdotal reports of death in otherwise healthy patients. Several potential etiologies exist for such problems, including arrhythmias or hypertension from stimulant medications (diet pills), acute electrolyte disturbances, or primary effects of the diet on myocardial contractility. These problems may be related purely to the diet or dieting practices or may result from the exacerbation of a previously undiagnosed condition (long QT syndrome).

Both acute and chronic adverse effects have
have been reported from over-the-counter and prescription diet pills. Many of these medications contain sympathomimetic agents, which act to control hunger as well as to increase the basal metabolic rate. Similar physiologic effects are seen with thyroid supplements, which have also been used to increase the basal metabolic rate in an attempt to facilitate weight loss. While these pharmacologic agents may be effective in these respects, significant adverse effects related to their effects on the cardiovascular system (arrhythmias, hypertension, myocardial ischemia) and the central nervous system (tremulousness, insomnia, psychosis, and seizures) may occur. Dieter and Vorperian reported the case of a 59-year-old woman who was using an over-the-counter diet medication containing the sympathomimetic ephedrine, who had cardiac arrest and polymorphic ventricular tachycardia. The patient was resuscitated successfully and subsequent electrophysiologic workup revealed no etiology other than the diet pills.

In addition to the potential arrhythmogenic effects of diet pills containing stimulants and sympathomimetics, their effects on heart rate and systemic vascular resistance can increase myocardial oxygen consumption to the point where an imbalance occurs between the supply-and-demand ratio, resulting in myocardial ischemia. Gibbins reported the case of a 37-year-old woman who had chest pain, arm pain, and subsequent ventricular fibrillation while using thyroid supplements, a sympathomimetic agent, and thiazide diuretics to facilitate weight loss. He concluded, “The common use of inappropriate prescription drugs for the treatment of obesity, even in patients without underlying organic heart disease, can be hazardous and may result in sudden catastrophic events.”

In addition to acute effects described, recent history reminds us of the potential for chronic effects from diet pills. Fenfluramine and dexfenfluramine were introduced into clinical practice as replacements for the sympathomimetic agents. Since they lacked the sympathomimetic effects of previously-used agents, their potential for morbidity and mortality was thought to be limited. They were subsequently withdrawn from clinical use when a significant proportion of patients had cardiac valvular lesions and pulmonary hypertension after long-term use of these drugs.

Aside from the direct effects of diet pills on cardiac function, with their potential for arrhythmias or myocardial ischemia, past clinical experience shows additional morbidity of dieting and dieting practices. The potential for morbidity and mortality related to dieting is highlighted by the experience from the 1960s and 1970s, with reported deaths in patients using liquid protein products. One potential etiology for these deaths was presented by Isner et al., who reported on the clinical and morphologic findings in 17 patients who died suddenly while using the liquid protein diet. Of the 17 patients, 16 were women and all had lost a significant amount of weight (mean loss of 35% of their body weight over a 5-month period). Eight of the patients had one or more episodes of syncope. Multiple-lead electrocardiograms (ECGs) from 10 patients were available and showed ventricular tachycardia and prolongation of the Q-T interval. The authors concluded that semi-starvation, using a very-low-calorie diet is a cause of acquired Q-T prolongation. Other potential etiologies of the Q-T prolongation, including drug-related causes and alterations in potassium, magnesium, and calcium, were ruled out. Autopsy findings showed myocardial fiber atrophy and increased lipofuscin pigment.

In many of the reports, the exact cause of death could not be definitely determined and may have been related to a direct toxic effect of the diet, starvation-induced myocardial atrophy or degeneration, electrolyte imbalance, arrhythmogenic effects of diet pills, preexisting repolarization defects (long QT syndrome), or myocardial ischemia. A full review of the investigations and potential etiologies for these deaths is outlined by the review of Surawicz and Waller.

Subsequently, additional anecdotal reports surfaced regarding morbidity and mortality during dieting using a very-low-calorie diet. These reports noted cardiac complications, including decreased QRS voltage, prolonged Q-T interval, ventricular arrhythmias, and cardiac arrest related to a very-low-calorie diet. Patients with a preexisting prolonged Q-T interval corrected for heart rate (QTc) and those who experienced excessive weight loss were thought to be at higher risk. Thwaites and Bose described an adolescent on a physician-prescribed very-low-calorie diet who lost 24 pounds in 2 weeks. She subsequently had a syncope episode, and an ECG showed classic ventricular tachycardia with numerous episodes of torsades de pointes. Later, the patient was found to have a preexisting prolonged QTc.
children (aged 7.7 to 15 years) who were treated with a commercially prepared very-low-calorie diet with that of 1 child who ate a homemade dietary regimen. Caloric intake was similar between the 2 diets; however, the homemade regimen was deficient in sodium and calcium. On day 14, the patient receiving the homemade regimen had arrhythmias, including couplets and nonsustained ventricular tachycardia, thereby potentially implicating electrolyte and mineral imbalance in the etiology of dieting-related mortality.

Additional evidence for the potential role of electrolyte, trace element, and mineral disturbances as the culprits in the morbidity and mortality from very-low-calorie diets and liquid protein diets is provided by Amatruda et al. In a prospective evaluation of 6 moderately obese patients who were treated with a 300 kcal liquid protein diet, they noted arrhythmias on 24-hour ambulatory Holter electrocardiograms. There was no association with any single metabolic imbalance or combination of metabolic imbalances. Evidence for the potential role of electrolyte, mineral, or trace element deficiency as an etiologic factor was provided by the follow-up study, which showed no evidence of arrhythmias in patients following the same diet supplemented with minerals, electrolytes, and trace metals.

Another factor that may account for morbidity and mortality related to dieting is the onset of ketosis related to decreased caloric intake, with the mobilization of tissue-stored lipids via lipolysis and release of fatty acids into the blood stream. This ketosis may be augmented by the inclusion of low carbohydrate intake, and, therefore, low endogenous insulin production. Low-carbohydrate/ high-protein/ high-fat diets have fallen in and out of popularity since the 1960s, resurfacing in various forms, including the Stillman Diet, the Scarsdale Diet, the Zone Diet, the Carbohydrate Addicts' Diet, and the Atkins Diet. These plans are attractive to many dieters because they set no limit on the amount of certain types of foods that can be eaten, propose to exclude hunger from the dieting experience, reduce appetite, and, at times, produce steady weight loss, even after dramatic failures or weight gain on other diets. Few data from prospective, controlled clinical studies have evaluated the long-term physiologic consequences of such diets, however. These diets are based on several suppositions. Their promoters suggest that obese patients make less efficient use of insulin and overproduce insulin in response to a carbohydrate load, which favors conversion of carbohydrate to fat rather than to energy, even when there is an ongoing energy requirement. It is suggested that the chronically high insulin level in obese patients prevents the liberation of fat stores during times when normal weight loss would occur, such as short fasts and overnight sleep. When a greater quantity of carbohydrate is ingested than can be used immediately or stored as glycogen, the excess is converted into triglycerides and transported to adipose tissue to be stored as fat. A secondary premise is that triglycerides do not stimulate the release of insulin and that amino acids do so only in the presence of a simultaneous glucose load. Therefore, on a low-carbohydrate diet, a state of dietary ketosis is achieved, regardless of the amount of fat-rich and protein-rich food consumed. A catabolic state is maintained, allowing weight loss with no intake limitation. With a high-protein/ high-fat intake, there is the release of cholecystokinin, a known appetite suppressant. The lack of glucose in the diet also inhibits the 1-hour post-prandial insulin surge associated with the stimulation of neurogenic feeding centers. Additionally, the increased reliance on fat to meet metabolic demands results in the production of ketone bodies, which may also suppress the appetite and curb feelings of hunger.

Low-carbohydrate/ high-protein diets are not without potential for adverse biochemical and physiologic consequences, however. Ketone bodies compete with uric acid for renal tubular excretion; ketogenic diets increase serum uric acid concentrations, which can exacerbate disease in patients with gouty diathesis. Bloom and Azar have reported that subjects on low-carbohydrate diets can have postural hypotension. Using an isolated, perfused rat-heart model, Russell and Taegtmeyer showed that the beating heart loses contractile function (more than 50% loss of function in 60 minutes) when oxidizing acetate alone. Elevated levels of free fatty acids may promote both vascular thrombosis and cardiac arrhythmias. Plasma lipolysis and infusion of albumin-bound free fatty acids have been shown to lead to the development of arrhythmias in animal models, possibly through a detergent effect on mitochondrial and cell membranes. These diets have also been associated with hypothyroidism, characterized by decreased levels of thyroid-stimulating hormone and triiodothyronine. Stockholm et al have shown that the decrease of stroke volume and cardiac index that occur with a very-low-calorie diet can be prevented by the concomitant administration of thyroid supplementation using triiodothyronine.
The potential role of these physiologic factors in the morbidity and mortality of dieting remains to be determined; however, given previous reports showing alterations in the histology of the myocardium, alterations in myocardial structure and function may play some etiologic role.

Restriction of caloric intake to less than the basal needs results in catabolism of protein and glycogen stores, which have a high water content, leading to a diuretic effect and the loss of free water and electrolytes. Additionally, mobilization of peripheral fat stores and a high fat intake leads to a ketotic state with the production of various ketone bodies, including acetoacetate and β-hydroxybutyrate. These ketone bodies undergo urinary excretion with a cation to maintain electrical neutrality, resulting in the additional loss of cations, including calcium, magnesium, and potassium. When compounded by inadequate intake, deficiencies of these cations may ensue. Mao et al found altered cardiac-conduction function in rats fed a high-fat, marginal-copper diet, suggesting another trace mineral that may have some role in dieting-related cardiac problems.

In addition to its use in weight loss, non-calorie-restricted ketogenic diets have been used for several years for the treatment of seizure disorders in children that are resistant to standard therapy. Best et al evaluated 20 patients receiving a ketogenic diet and noted a prolonged QT interval in 3 patients. There was a correlation between QT prolongation, decrease in serum bicarbonate level, and increase in serum β-hydroxybutyrate level. Three additional patients had echocardiographic evidence of cardiac chamber enlargement, while 1 patient had severe dilated cardiomyopathy with pulmonary edema, which resolved after discontinuance of the diet.

The final potential factor that may play a role in the etiology of dieting-related morbidity and mortality is direct myocardial effects related solely to inadequate caloric intake. Starvation, regardless of its cause, results in atrophy of the heart, bradycardia, right shift of the QRS axis, decreased QRS complex and T wave amplitude, and QTc interval prolongation. Autopsy studies have shown histologic alterations of the myocardium, including atrophy, ganglionitis, and neuritis.

**SUMMARY**

Approximately 60% of adolescent females and 25% of adolescent males have diets at some point in their lives (Table 1). Among these adolescent dieters, a significant percentage report unhealthy or dangerous weight-loss methods, including use of diet pills, fasting, skipping meals, or using very-low-calorie diets (Table 2). Dieting can be associated with both positive and negative consequences. Dieting adolescents report more health-promoting behavior, such as increasing fruit and vegetable intake, decreasing fat intake, and increasing exercise; however, dieting in adolescence is also associated with increased health-risk behavior, such as alcohol and tobacco use, delinquency, and suicide attempts. Additionally, dieting is often undertaken by adolescents who are not above the ideal or normal body weight for their age and physical stature.

Dieting appears to have more negative than positive consequences on the psychologic health of adolescents. Adolescent weight-loss behavior is associated with poor body image, negative psychosocial risk factors, and possibly decreased coping mechanisms, leading to decreased self-esteem. A strong correlation between dieting and the onset of eating disorders exists. One of the most alarming issues regarding dieting is the report of associated mortality. While many of the reports are anecdotal and the majority of patients diet without sequelae, scientific data support potential adverse physiologic consequences of dieting and weight loss, including loss of electrolytes, minerals and trace metals, histologic changes of the myocardium, as well as the potential adverse effects of free fatty acids on myocardial function. Alterations of electrolytes (sodium, potassium, magnesium, and calcium), minerals, and trace metals may be related to decreased intake (anorexia, deficient diets) or increased losses from the gastrointestinal tract (bulimia or laxative use) and the kidneys (ketosis).

Given all of the potential consequences of dieting and its associated behaviors, obesity prevention should be the primary intervention point, with improved education of parents, adolescents, and children regarding appropriate eating patterns and behaviors. When weight loss is necessary, the most appropriate method remains modest caloric restriction incorporating a balanced intake of macronutrients and micronutrients, along with increased physical activity. Considering the previous reports of serious cardiac sequelae, very-low-calorie diets or ketogenic diets should be undertaken only under a physician's direct supervision, with a pre-diet ECG and frequent cardiac monitoring during the course of the diet. The common
and the potential for cardiac dysrhythmias. When such diets are followed without supplementation, alterations of electrolytes, minerals, and trace elements may result in Q-T prolongation and the potential for cardiac dysrhythmias.

References


