Consequences of Sport-Imposed Weight Restriction in Childhood

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Key Words

Childhood sport • Weight restriction • Growth, childhood • Maturation

Abstract

Today, young competitors undertake training programs including a high level of physical activity from an early age. This intensive training (volume and intensity) increases energy expenditure which has to be compensated by a greater nutritional intake. Ballet dancers, figure skaters, gymnasts or rhythmic gymnasts start training at the age of 5–6 years and most of them practice more than 20–30 h/week. In these activities, as well as for weight-class sports (wrestlers, jockeys, judo or boxing athletes), young elite athletes make conscious decisions to reduce food intakes to maintain the slender, pre-pubertal physique or to 'make weight'. Adequate energy and micronutrient intakes are essential for growing children, and caloric and fluid restrictions during physical training in childhood or during adolescence could disturb metabolic and hormonal regulations affecting growth, maturation, body composition, menstrual cycle and reproductive capacity, and may increase the risk of injuries such as stress fractures. Furthermore, these strategies may develop eating disorders (anorexia and/or bulimia nervosa), especially during female adolescence, affecting body image, self-image and developing social and emotional maladjustments.

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Introduction

During childhood and adolescence, rapid growth and development increase energy and micronutrient requirements. The nutritional needs are greater in young athletes due to the higher level of physical activity. Food and fluid restrictions in young elite athletes are extensive, especially in aesthetic and weight-class sports, and may potentially be dangerous during the growing period. The aim of this review is to report the potential adverse health effects of sport-imposed weight restriction in childhood.

Food and Fluid Restrictions in Specific Sport Categories

Energy, Macro- and Micronutrients

During childhood and adolescence, rapid growth and development affect energy, macro- and micronutrient needs.

Energy

Due to great intra- and inter-individual variability, there are some difficulties to quantify the estimated energy requirements in the athletic or very active child or adolescent. The Food and Nutrition Board's calculation for the estimated energy requirements is based on equa-

tions including an individual's age, height, body weight and a physical classification of sedentary, moderately active, active, and very active life style [1]. Among 9- to 13-year-old children, energy needs range from 1,415 kcal/day for the sedentary 9-year-old girl to 3,038 kcal/day for the very active 13-year-old boy. Among 14- to 18-year-old adolescents, energy requirements range from 1,718 kcal/day for the sedentary 14-year-old girl to 3,804 kcal/day for the very active adolescent of 18 years. Thus, the total energy expenditure in child and adolescent athletes is linked to basal energy, growth and the level of physical activity. For example, in elite gymnasts, physical training increases caloric demands and induces an additional 400–700 kcal energy intake/day [2, 3].

Energy Intake in Sports with Weight Restriction

In order to remain lean and to keep a juvenile physique, many elite gymnasts, rhythmic gymnasts, ballet dancers and figure skaters are convinced that they have to be on a diet. In weight-classification sports (wrestlers, judo or boxing athletes), food and fluid intake restrictions are commonly practiced throughout the competitive season to compete at one to three weight classes below their normal weight [4] in the belief that they will gain a competitive advantage over smaller opponents. Thus, repeated cycles of weight loss and regain are usual and the energy intakes are regularly disturbed [5, 6]. These 'weight cuttings' and regains have been associated with reduced energy requirements due to a decreased metabolic rate in young athletes [7].

Although limited, a few studies have shown that all along the training program (gymnasts, rhythmic gymnasts, ballet dancers, etc.) or throughout the competitive season for weight-class athletes, the energy intake is theoretically insufficient to support growth and vigorous training [8–20].

Protein

Sufficient protein intake is required to provide essential amino acids which support growth, and especially the maintenance and development of lean body mass. Indeed, protein metabolism is important for lean tissue growth and remodeling. Heavy and regular exercise training increases the daily protein requirements in adult athletes [1, 21]. Recommended protein intakes for sedentary or moderately active children and adolescents (between 9 and 18 years) range from 0.73 to 0.85 g/kg [1] or 0.80 to 1.0 g/kg body mass [22, 23]. However, this recommendation is not based on active or very active children. Actually, no data are available on the protein requirements of young ath-

letes. In most cases, young competitors spontaneously increase their food intake for energy and naturally meet their protein needs. In sports leading to food restriction behaviors, protein metabolism could be disturbed and thus, impair growth and/or total fat-free mass.

In gymnasts or ballerinas, even if nutritional assessments indicate that many of these young girls have a caloric intake inferior to the usual recommended dietary allowance [1] for their age and physical activity level [17, 24–27], the protein intake spontaneously appears to be greater than 0.8–1.0 g/kg/day and most of the time reaches 1.3–1.8 g/kg/day. In fact, as reported in different nutrition studies, these athletes consume excess protein at the expense of fat and carbohydrates [27]. Furthermore, a recent study using the stable isotope ^{15}N -glycine indicates that training does not affect protein turnover in pre- and early pubertal female gymnasts [17].

The attitude concerning young elite wrestlers or judo athletes is quite different. Thus, different publications have shown that the nutritional protein status may be altered during the period of 'weight cutting' [28], which could induce a temporary negative nitrogen balance leading to possible growth disruptions and muscle injuries. Recently, Friedlander et al. [29] indicated that a 3-week caloric restriction alters protein metabolism (leucine turnover and oxidation) in normal-weight young men.

Carbohydrate

The dietary reference intakes for carbohydrate are based on the amount needed to provide glucose to essential tissues (such as the brain) and do not consider the needs of muscle or liver glycogen replacement. In adults, the performance in prolonged or repeated high-intensity exercise is linked to the total glycogen stores since carbohydrate is the limiting fuel for maintaining the work rate [30, 31]. In pre-pubertal children, glycolytic capacity is supposed to be less efficient than in adolescent or adult subjects, which induces an enhanced fat utilization during prolonged exercise in young athletes [32]. Whether or not young competitors benefit from a high level of carbohydrate intake has still to be determined. The recommended carbohydrate intake is 50–60% of the total daily energy intake with only 10% of simple sugars [33].

Gymnasts or ballet dancers believe that carbohydrates are high-calorie foods. Although the mean intake of carbohydrates in gymnasts, ballerinas, figure skaters, for example, is $\pm 50\%$ of the total energy intake, it is predominantly with simple sugars rather than complex carbohydrates [8, 17, 24, 27, 34]. These nutritional surveys indicate that the preference for sweet flavors is not well adapted to

increase muscle and liver glycogen stores. In weight-class sports, the restricted diet might also induce a significant decrease in muscle and liver glycogen content just before the competition [5].

Lipid

There is no adequate intake or recommended daily allowance set for total lipids but the adequate intake levels exist with regard to essential fatty acids, linoleic and linolenic acids (n-3 and n-6; table 1).

It is recommended that 30% of the total energy intake comes from fats in children or adolescents [1, 33]. Although children use proportionally more fat as an energy source during prolonged exercise than adults, there are no data to suggest that they need a greater lipid intake.

Concerning the purpose of weight control or weight restriction, it is usual to suggest a decrease in lipid consumption. A total energy intake decreased by fat reduction may be a dangerous strategy in children or adolescent athletes. Indeed, a minimal amount of body fat is required to ensure metabolic and hormonal adaptations. The recommended level for sustaining health and fitness is 7% for males and 14% for females [35]. The reduction, or even the exclusion, of fat products is an aberration involving monounsaturated and polyunsaturated fat deficiencies. Furthermore, fat products such as dairy food and red meat contain high-quality protein, calcium, magnesium, iron, zinc, chromium, vitamin B₁₂, fat-soluble vitamins, etc., which are necessary to optimize growth. All the nutritional surveys on aesthetic sports, including ballet dancers, figure skaters, gymnasts and rhythmic gymnasts, indicate an insufficient lipid intake [8, 11, 17, 24, 27]. In weight-class sports, the fat distribution widely oscillates between the 'weight-loss' and 'weight-making' periods ('yo-yo' diet). As a consequence, the body fat percentage is perpetually modified which probably disrupts lipid metabolism during the growing state.

Micronutrients

Inadequate energy intakes are generally accompanied by marginal micronutrient intakes (minerals and vitamins). Indeed, in studies in which young athletes reported caloric restriction, micronutrients failed to meet recommendations [5, 6, 8, 17, 24, 34, 36, 37]. Studies surveying dietary intake in active children and adolescents or in young athletes commonly identify deficiencies of two important micronutrients: calcium and iron. These micronutrients are critical not only for good health but also in optimizing athletic performance. Iron functions as a component of a number of proteins, including enzymes, he-

Table 1. Adequate intake levels for linoleic and linolenic acids

Age	Fatty acid, g/day	
	linoleic acid	linolenic acid
9–13 years		
Boys	12	1.2
Girls	10	1.0
14–18 years		
Adolescent boys	16	1.6
Adolescent girls	11	1.1

moglobin and myoglobin, the latter being important for the transport of oxygen to tissues throughout the body for metabolism. Iron deficiency induces anemia and impairs performance. Calcium is also an important micronutrient for the development of bone mass, a process that may protect against osteoporosis in adulthood. Over 99% of total body calcium is found in teeth and bones. The remainder is present in blood, extracellular fluid, muscle and other tissues, where it plays a role in mediating vascular contraction and vasodilatation, muscle contraction, nerve transmission and glandular secretion.

Puberty increases the requirements for iron and calcium due to increases in hemoglobin mass, tissue deposition, growth spurt, and the onset of menstruation in females. In sports with energy restriction, dietary calcium and iron are very low [38, 39] since young athletes shun dairy foods and red meat either from concern over fat intake or the desire for a vegetarian diet.

Fluids and Exercise

Hydration status prior to participating in physical activity or sports is an important indicator of performance and endurance, and may limit injuries in adults as well as children or adolescents. Fluid intake is recommended prior to, during and at the end of exercise. Fluid deficits at the end of physical activity should be replaced based on weight loss.

Scientific information on weight-class sports remains scarce with regard to dehydration strategies. However, from a practical point of view, these athletes restrict all fluids before the competition (water, sodas, coffee, soup, etc.) and, in addition, by using plastic underwear, they generally sweat during intensive exercises to stimulate water-weight loss. Other strategies such as saunas, diuretics, vomiting are usually experimented with in the attempt to 'make weight' [5, 28]. The expected benefit of fluid restric-

tion and acute dehydration strategies appears to be a rapid weight loss that allows the athletes to compete in a specific category. This strategy, as shown below, is not without consequences.

Potential Consequences on Health

The difficulty here is to establish causality between food and fluid restrictions and 'health' effects. Indeed, the total interaction between genetic and environmental factors (as nutrition) make the demonstration difficult. However, further studies support the explanation of potentially negative health effects induced by weight restriction in child and/or adolescent athletes.

Growth and Maturation

Despite the 'normal' short stature of elite gymnasts, rhythmic gymnasts or ballet dancers and the obvious health benefits of physical activity during growth, there is a concern that competitors of 'aesthetic sports' involved in high-level training programs may be at risk of adverse effects on growth and maturation. Indeed, in the absence of sufficient nutrition to compensate for the increased level of physical activity, the energy demands of training may compete with those of the cellular processes underlying normal growth and maturation for available energy, especially during the adolescent growth spurt [40].

For example, female gymnasts have less fat mass than controls and are also significantly shorter and lighter for their age, with differences more important among older, advanced level gymnasts [41]. Most of the time, sexual maturation is delayed in male or female gymnasts compared with their less active twins and/or siblings. Even if longitudinal growth studies offer more insight than cross-sectional data, they still do not prove causation [42]. However, most of them indicate attenuated growth and delayed maturation in young female athletes involved in intense training programs, and numerous data indicate catch-up growth when the total amount of training is decreased and/or when the diet is sufficient [for details, see 42]. Frequent reports indicate energy restriction among adolescent female athletes at an advanced competitive level. This mechanism could explain the adverse effect on growth and maturation since the pubertal growth spurt is sensitive to nutritional factors. The mechanisms between food restriction and attenuated growth and maturation in children and adolescents are, in part, due to lesser circu-

lating concentrations of growth-related hormones. Indeed, we know that chronic caloric and protein restrictions decrease the level of insulin-like growth factor-1 (IGF-1) [43]. As compared to controls or swimmers, IGF-1 plasma levels are lower in young female gymnasts and are associated with insufficient energy intakes, delayed maturation and disrupted growth [44–46]. In contrast, IGF-1 plasma concentrations are not reduced in pre- and early-pubertal male gymnasts as compared to controls [47], but it is well known that the limited dietary intake is always more pronounced in girls.

Body Composition

Body composition differs according to the sport. In sports imposing weight restriction, there is variability in the relative body fat and lean body weight measures between aesthetic sports and weight-class sports since weight fluctuations appear in the second category.

Body Composition in Aesthetic Sports

Most of the time athletes who participate in sports in which appearance is an important factor for success are very thin since they consciously initiate a restrained diet to maintain a pre-pubertal physique with low body weight and low fat mass. As a consequence, extensive literature has shown that pre-, early-pubertal and college-age gymnasts, rhythmic gymnasts or ballet dancers are characterized by a low or very low percentage of body fat [for review, see 48]. Paradoxically, studies in athletes or non-athletes have demonstrated that the human adaptive response to energy restriction is a reduction in the resting metabolic rate, with a possible increase in fat storage [49]. For this reason, it becomes more and more difficult for these athletes to keep a low body fat mass, and then when competition ends, an alteration in adipose tissue is usually observed with an increase in total fat cell size and/or fat cell number [15].

Generally, energy imbalance created by a high level of physical activity and diet restriction is associated with lower bone density [49]. However, even if calcium intakes are reduced in aesthetic athletes such as gymnasts, figures skaters, ballet dancers or rhythmic gymnasts, these young female and male athletes have a significantly higher bone mineral density than other athletic groups or non-athletic control groups [48]. Both genetics and also the strain on bone (repeated jumps and dismounts) contribute to higher bone mineral density. Thus, whatever the nutritional intakes, bone mineral and even bone size are elevat-

ed in elite athletes involved in very high impact activities.

Body Composition in Weight-Class Sports

In sports with specific weight categories such as wrestling, judo, etc., weight fluctuations are rapid, frequent and large. Thus, body composition may be regularly modified. Weight losses over the short-term are predominantly composed of water, fat, protein, and glycogen. When the athletes lose weight and fat stores, the distribution of body fat may change. With the duration of energy restriction, the contribution of fat stores to total weight lost increases substantially. However, most of the time the young athletes carry out a rapid diet and lose weight over short periods, which leads to significant losses of lean tissue and water [5, 15]. Reducing the magnitude of energy deficit and increasing the duration of the weight loss period should minimize the loss of lean tissue and maximize the loss of fat. When athletes lose and regain weight, fat stores may be lost and then regained in different areas of the body [15]. If fat is lost from one site and regained in another, the distribution of fat could be modified even if the total fat remains similar. Little is known about weight gain patterns in former weight-class athletes, but later on the 'yo-yo diet' could induce an elevated waist/hip ratio indicating a risk of cardiovascular diseases as in obese people.

Food Efficiency

Food efficiency can be defined as the ratio of weight change to ingested calories. It represents an index of how much a person must eat to maintain a given weight or body composition. If food efficiency increases, the caloric intake necessary to sustain 1 kg of body weight decreases. From different studies looking at nutritional intakes and body composition in young male and female athletes, Brownell et al. [15] speculated that food efficiency could be enhanced in athletes with low or fluctuating weights. This mechanism is probably a physiological adaptation facilitating energy stores as a vital process. However, when caloric intake is increased, weight gain could rapidly appear. Anecdotally, some female gymnasts complain that keeping their weight low becomes more and more difficult leading them into a chronic struggle.

Menstrual Dysfunction and Reproductive Capacity

Dixon et al. [50] suggested that high levels of physical activity result in an increase in the secretion of endorphins, and this in combination with caloric restriction produces an abnormal regulation of hypothalamic activity. Dysregulation of the hypothalamus sparks off the decrease in the pulsatile frequency of gonadotropin secretion (follicle-stimulating hormone, luteinizing hormone) and frequently induces retardation in pubertal maturation and consequently oligo- or amenorrhea [8]. Regulation of the hypothalamus-hypophysis varies greatly from one sport to another. It is well known that elite gymnasts tend to have a delayed age at menarche and menstrual dysregulation (amenorrhea, oligomenorrhea, anovulation, luteal phase deficiency) due to hormonal alterations caused by dieting and the training program [51]. If amenorrhea represents the most extreme form of menstrual dysfunction, other forms can also result in suppressed estrogen levels and affect bone health and fertility. Thus, physically active girls and adolescent females performing aesthetic sports can theoretically develop the 'female athlete triad', a syndrome consisting of three components: disordered eating, amenorrhea and osteoporosis (even if the third one is less usual in high-impact activities as shown above).

Suppressed or decreased testosterone levels in males may be the parallel of menstrual dysfunction in females. Strauss et al. [52] found low serum testosterone levels in male wrestlers, especially when the percent body fat dropped below 5%. Levels returned to normal after the season when weight increased. Thus, low body weight, low body fat, undernutrition, and/or a high level of training may pose a threat to the reproductive capacity of male athletes.

Iron Status and Anemia

Low levels of blood hemoglobin (13–14 g/100 ml in males and 12 g/100 ml in females) in addition to low hematocrit and ferritin (<20 µg/l) levels are frequently observed in trained athletes. These parameters define the concept of 'sports anemia' [53]. The hemoglobin mass increases with puberty. To this end and due to tissue deposition, growth spurt and onset of menstruation in females, the iron requirement is more elevated during the pubertal period [33]. Low iron levels may be due to mechanical hemolysis, intestinal bleeding, hematuria, sweating, low iron intake or poor intestinal absorption [53]. The result-

ing decrease in blood gas transport and muscle enzyme activity impairs performance. Few studies have examined iron status in adolescent athletes, but it seems that these athletes, as adults, are also prone to non-anemic iron deficiency [54, 55]. On the other hand, evidence of depleted iron stores (low ferritin levels) is reported in female and male gymnasts [38].

Injuries

Many investigations have examined injuries in young elite gymnasts. Retrospective and prospective studies show that injury rates for female gymnasts are high and positively associated with the performance level. Acute injuries (e.g. stress fractures and ligament sprains) to the feet and toes are common as are ankle injuries [48]. Some of these acute injuries could be due to dietary restriction since it is well known that low estrogen levels, insufficient protein and calcium intakes, combined with a late menarche, potentially lead to an increased rate of stress fractures [56].

During weight-loss strategies in weight-class sports, it is usual to observe musculoskeletal injuries due to fluid deprivation before competition [35]. The possibility of suffering a heat injury is also present if the competition is performed in a severely heated environment.

Dehydration Effects

Severe weight reduction might actually impair physiological functions. For instance dehydration could impair the kidneys by reducing plasma flow and filtration. Young wrestlers also have reported instances of irritability, constipation and 'feeling flat' [37]. The effects of rapid weight loss and dehydration on physiological performance are well documented [35]. This practice might cause: a reduction in muscle strength and anaerobic power capacity; increased resting and submaximal heart rate; decreased cardiac stroke volume resulting in a decreased ability to sustain work at a constant rate; lower oxygen consumption; impaired thermoregulatory processes; lower plasma and blood volume; depletion in muscle and possibly liver glycogen; difficulty in glucose homeostasis; altered hormonal status; reduced immune function, and so forth [35]. In addition, *in vitro* research has suggested that dehydration of cells can lead to the initiation of protein and glycogen breakdown as a means to adjust cellular osmolarity in response to a decreased intracellular fluid volume [57].

Eating Disorders

Eating disorders may be defined as eating or not eating in response to an external cue rather than an internal one. Eating disorders in the female athletic population are receiving increasing attention. Athletes performing in sports that require leanness and/or a specific body weight are more prone to develop eating disorders than other athletes [58]. Thus, competitive rhythmic sport gymnasts, gymnasts, ballet dancers, figure skaters, for example, are accused of promoting an unphysiologic weight reduction which may progress to manifest anorexia and/or bulimia nervosa [58]. The enormous pressure on young athletes to be successful and achieve an ideal body weight may explain this fact. Thus, athletes in 'thin-build' sports report greater body dissatisfaction, low self-esteem and more persistent dieting than other athletes. The inability to control weight and body shape can lead to frustration, guilt, and even despair which may induce social and emotional disturbances.

Morbidity and Mortality

The dietary practices followed by some athletes may increase the risk of acute or chronic diseases. Aside from the specific quality of the diet (saturated fats, simple sugars, sodium, etc.), body weight patterns could also influence health. It is well known that chronic calorie restriction reduces the risk of certain cancers [59] and decreases coronary disease, hypertension and diabetes. However, athletes with low weights and eating disorders may suffer from important nutritional deficiencies (e.g. vitamins, minerals, essential amino acids, essential fatty acids) which may alter metabolic and organic functions. For example, patients with anorexia nervosa have a greater QT dispersion than constitutionally thin and normal-weight females due to very low potassium levels (QT dispersion was defined as the difference between the longest and the shortest QT interval occurring in the 12-lead ECG) [60]. In the same way, repeated bouts of loss and regain may create different negative effects on health. Indeed, weight loss is associated with decreased blood pressure, and gain with increased pressure. The increase period being more important than the decrease period, blood pressure may be affected. Furthermore, different studies have suggested that renal ischemia may result from weight cycling in wrestlers, which could predispose them to later hypertension [15].

Conclusion

As shown in this review, the consequences on health of sport-imposed weight restriction in childhood are numerous and sometimes irreversible. To avoid these dramatic effects, we recommend that the nutritional status of highly active young athletes be carefully monitored, re-

gardless of their age, sport and gender, especially those engaged in sports characterized by a limited food intake (aesthetic sports) or irregular food consumption (weight-class sports). A psychological approach and nutritional education for athletes, trainers, parents, etc., should complete the dietetic advice made by a sport dietician or nutritionist.

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