Nutritional Considerations for the Overweight Young Athlete

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Nutritional considerations for the overweight young athlete have not been thoroughly discussed in the scientific literature. With the high prevalence of childhood obesity, more children participating in sports are overweight or obese. This is particularly true for select sports, such as American football, where large size provides an added advantage. While sport participation should be encouraged because of the many benefits of physical activity, appropriate nutritional practices are vital for growth, and optimizing performance and health. The overweight young athlete may face certain challenges because of variable energy costs and nutrient requirements for growth and routine training, compared with nonoverweight athletes. Special attention should be given to adopting healthy lifestyle choices to prevent adverse health effects due to increased adiposity. In this review, we aim to discuss special nutritional considerations and highlight gaps in the literature concerning nutrition for overweight young athletes compared with their nonoverweight peers.

The prevalence of childhood obesity has increased drastically over the past few decades. Although the rate of increase appears to be slowing down or leveling off (42), there remains a great number of youth affected by obesity. The World Health Organization (WHO) cut-points for overweight and obesity are defined as one or two standard deviations above the mean for body mass index (BMI) percentile for age, which is approximately the 84th and 97.7th percentile, respectively (128). Based on WHO cut-points, 31.5% of Canadian youth ages 5–17 years are overweight (19.8%) or obese (11.7%) (103). Similarly, 31.8% of youth are classified as overweight (14.9%) or obese (16.9%) in the United States (90), however, these prevalence rates were based on the Centers for Disease Control and Prevention (CDC) cut-points. CDC classifies overweight and obesity as ≥85th and ≥95th BMI-for-age percentile, respectively. Prevalence rates determined by WHO cut-points are not significantly different from when CDC cut-points are used (113). Abdominal obesity, as assessed by waist circumference, should also be considered when predicting future health risks. Evidence suggests that individuals with higher abdominal obesity have an increased morbidity and mortality risk (61). The prevalence of abdominal obesity in Canadian youth ages 12–19 years has increased from 1.8% in 1981 and 2.4% in 1988 and to 12.8% in 2007–2009 (62). These statistics provide great concern for the increased risk of metabolic complications developing during childhood.

Consequently, preventative strategies to reduce health risks related to obesity are necessary.

The purpose of this narrative review is to provide an overview of weight management strategies in the context of nutrition and exercise. The review will discuss unique nutritional considerations for overweight children who want to be active through participating in sport. Increasing energy expenditure may benefit overweight children by elevating the utilization of excess energy stores. Sport participation appears to be a feasible and acceptable way to increase energy expenditure and potentially reduce weight gain in children (127). Nutritional advice and education is important for promoting optimal conditions for training and sport performance. The available resources for young athletes are geared toward nonoverweight children, and do not include data on weight status (6,76,84,91). Thus, nutrition for overweight young athletes is a topic that requires further discussion.

Expert Committee recommendations developed by a group of pediatric obesity experts suggested that treatment evaluations for overweight children should include a focused assessment of physical activity habits and diet (5). Weight-management programs are, unfortunately, not accessible to all communities and are often limited by resources; however, a lifelong pursuit of healthy eating habits and physical activity is critical for all children. Either within or outside of the clinical setting, a challenge is to find meaningful sources of physical activity for the child. While sport participation is an obvious choice, additional research and discussions on the efficacy of team sports for weight management are warranted. Currently, there is a paucity of observational data examining the influence of team sports on increasing regular physical activity and fitness, or reducing weight gain. A German

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study reported that children in organized sport more than once per week had greater physical fitness and were less likely to be overweight (33).

When examining cardiorespiratory fitness versus fatness, it appears that fatness has a stronger association with components of the metabolic syndrome than fitness in children (37). Furthermore, data in men show that within categories for BMI or abdominal fat, fitness attenuates cardiovascular disease risk factors (68). Weight management strategies for active overweight youth should go beyond assessing BMI and consider improving fitness and reducing abdominal fat, which are not often reported in studies. The role of physical activity and sport participation on this relationship is another area that requires further study.

Recent findings from a pilot randomized controlled trial providing an after-school soccer program versus health education for overweight children showed that children engaged in the soccer program had significantly lower BMI z-scores at 3 and 6 months than those with health education (127). Data on abdominal obesity and percent body fat were not reported, but waist circumference and skinfold thickness measurements will be included as secondary outcome measures in a follow-up study. Future research will assess the effectiveness of an intervention program that encourages team sport participation over a three year period (105).

Statistics on sport participation are limited, especially population data with information on overweight athletes. However, based on the available data, there appears to be a selection bias for participation of overweight young athletes in select sports (24,38). Although the physical demands on the body to keep up with their nonoverweight peers may be greater, overweight children have more muscle mass and absolute strength, as shown by greater knee extension and grip strength by Ervin and colleagues (39). Greater strength may compensate for possible disadvantages in quickness and agility. In addition, as individual's participate in an increasing number of athletic activities, BMI of participants tend to be lower, except for sports with higher demands of power and strength, such as American football (24,38). Elkins et al. (38) found that obesity was fivefold greater in boys who participated in football compared with other sports in a sample of inner city African American youth. In the Fairfax County Public School District in Northeastern Virginia, the prevalence of overweight and obesity (CDC cut-points) in 3970 young male athletes was 30.3% and 14.4%, respectively (24). The report increased concern for a higher prevalence of overweight or obesity in young male athletes when compared with NHANES (1999–2002) data, especially athletes involved with football, wrestling and/or rowing (24). Therefore, it is unreasonable to assume that all children with increased sport participation have lower BMIs compared with inactive children. One caveat in these reports on sport participation is that overweight was defined using BMI, which may be largely influenced by higher muscle mass. Whether these young athletes have greater abdominal

obesity than their nonoverweight peers should be assessed to identify future health risks. Unfortunately, these data were not available. Coaches should be careful to not reinforce poor health decisions if young athletes are being selected based on body size.

Most studies have classified overweight and obesity based on BMI. It is uncertain how many overweight young athletes have a healthy percent body fat, in which case weight loss may not be as relevant as maintaining weight and muscle mass. In a group of 203 schoolboy rugby players in Ireland, 68% were a healthy weight, 22% were underweight, and 9.7% were overweight (126) based on percent body fat groups defined by McCarthy et al. (73). This indicates that a proportion of young athletes remain classified as overweight based on excess adiposity. Larger studies to assess the prevalence of overweight, using percent body fat cut-points, in sport participation would be beneficial.

To excel in competitions or games, overweight athletes may have to work harder than nonoverweight athletes because of the extra energy expended to complete the same tasks. However, if energy expenditure is increased, should energy intake be increased or maintained in the overweight child? The extent to which nutritional considerations depend on the volume and intensity of training relative to body mass is rarely investigated. Furthermore, weight stigmatization or the physical demands of a particular sport may lead to additional stressors and poor nutritional choices of the overweight child. In this review, we aim to discuss special nutritional considerations and highlight gaps in the literature in overweight young athletes compared with their nonoverweight peers. We begin by providing an overview of energy requirements for children; literature on substrate utilization during exercise, macronutrient and micronutrient considerations, and hydration guidelines. While others have published work related to nutrition and the young athlete, none have specifically focused on the overweight young athlete. Potential psychosocial barriers for sport participation, which may indirectly impact dietary intake will also be presented briefly. We will use the term "children" to refer to individuals under the age of 18 years, unless nutritional information can be provided for a specific age-group.

Energy Requirements for Children

The nutritional requirements of children are different from adults, because children require additional nutrients for optimal growth and maturation, and should maintain a positive energy balance (energy intake > energy expenditure). Estimated energy requirements (EER) depend on age, sex, height, weight and the volume of training or physical activity level of an individual. It is difficult to establish precise energy requirements for children, because of the variable timing of the growth spurt, which does not occur at the same chronological age (82). EER suggested by the Institute of Medicine are divided into 4

physical activity levels (sedentary, low active, active and very active) (56). EER values are summarized in Table 1 (56). The calculation of EER values for nonoverweight children include total energy expenditure (TEE) and an estimate of energy deposition resulting from childhood growth.

Among overweight children, special considerations for EER are necessary for meeting weight goals. Rapid weight loss in children is not advised and could lead to stunted growth or micronutrient deficiencies (56). Expert Committee recommendations (5) on weight goals state that weight maintenance of a child's baseline weight should be the initial step for children ≥ 2 years. For children ≥ 7 years, continued weight maintenance is an appropriate goal if BMI remains between the 85th and 95th percentile with no comorbidities. However, in the presence of secondary complications related to obesity or a BMI above the 95th percentile, weight loss of about 0.45 kg per month (15 g/day or an energy reduction of 108 kcal/day) is suggested. The child with the help of his or her family should first show an ability to maintain weight before starting weight loss goals (5). TEE equations for weight maintenance among overweight children provided by the Institute of Medicine can be used to guide energy intake (56).

Defining precise energy requirements for overweight young athletes is challenging because of variability in energy costs associated with growth and individual training sessions compared with nonoverweight children and adults. When we observe energy costs at a given speed of locomotion, energy costs are greater in younger children than older children and adults when calculated per kg of body weight (65,70). This difference may be explained by poor coordination between agonist and antagonist muscle groups during a child's first 10 years. There is a higher demand for metabolic energy because the antagonist muscles do not relax sufficiently when the agonist muscles contract (43). Within a given age group, Morgan et al. (81) suggest that interindividual differences and changes in physical development and body structure may explain some variability in boys and girls. As a result, it is not appropriate to use adult tables to estimate energy costs for children. For more information on compendiums of physical activity energy costs in children and existing limitations, readers are directed to other references (9,52,81). Overweight children are likely to have greater energy costs than nonoverweight children and adults during walking or running conditions (3,66). Moreover, less is known about training responses of children compared with adults. Among obese children, 4 weeks of endurance training (5×1-hr sessions per week at 50–60% VO_{2max}) led to an increase in TEE by 12% (11). Approximately half of the increase was accounted for by the direct energy cost of training and half by the energy expenditure after training (11). No studies have compared similar training effects to nonoverweight youth using doubly labeled water. However, using accelerometry data, Bolster et al. (15) found nonoverweight children also increased energy expenditure associated with physical activity above baseline after a training program. Among nonoverweight children, physical training usually requires additional caloric intake on top of the calories needed to support growth and basal energy expenditure. Among overweight children, the intensity and volume of training sessions must be considered along with healthy weight maintenance or weight loss goals. Overweight young athletes may not have to increase daily caloric intake to compensate for the increased energy expenditure. This would likely lead to weight loss, which may be favorable for overall health if it occurs gradually over time, especially if it is accompanied by reduced abdominal obesity.

Among overweight children, caloric intake may vary significantly between individuals. We recommend that adjustments to dietary intake of overweight children be made with professional guidance, such as through regular follow-up visits with a physician or a dietician in a weight management program. Keeping track of the young athlete's diet over a typical week and assessing total caloric intake and available nutrients is a good starting point. This will help identify any critical nutrients that are missing from the diet and what foods may be consumed in excess. Completing a detailed assessment and journal of regular physical activity would also help track potential changes in energy expenditure. A better understanding of individual energy requirements is certainly valuable, but the macronutrient and micronutrient composition of a child's diet is also critical for sport participation and weight maintenance or weight loss. If overweight children do not exceed energy expenditure with higher energy

Table 1   Estimated Energy Requirements for Boys and Girls 9–18 Years of Age

		Estimate Energy Requirements (kcal/day)			
	Age (years)	Sedentary PAL	Low Active PAL	Active PAL	Very Active PAL
Boys	9–13	1530–1935	1787–2276	2043–2618	2359–3038
	14–18	2090–2383	2459–2823	2829–3013	3283–3804
Girls	9–13	1415–1684	1660–1992	1890–2281	2273–2762
	14–18	1690–1731	2024–2059	2334–2368	2831–2883

Note. PAL = physical activity level.

*Adapted from Institute of Medicine Dietary Reference Intake macronutrients report (56).

intake from fat, protein and carbohydrate (CHO), regular sport participation may help reduce excess fat accumulation and cardiovascular risk. The following sections will discuss energy metabolism in nonoverweight children and overweight children, as well as important considerations related to dietary composition for young athletes.

Protein Turnover

Protein provides the essential amino acids necessary for growth by promoting protein synthesis and maintaining lean body mass development. To retain a positive nitrogen balance, protein has to be ingested alongside sufficient energy intake so that protein is not used as a substrate for energy (91). Dietary modifications for obesity treatment are challenging because reduced caloric intake may subsequently lead to reduced protein turnover and greater protein utilization due to metabolic adaptations (115). Among obese children ages 8–10 years, a negative energy balance induced by a 6 week diet intervention showed reduced protein turnover, mainly due to slightly reduced protein synthesis. However, resting metabolic rate showed no changes with the intervention despite changes in protein turnover (36). Further research with longer duration longitudinal studies to examine reduced caloric intake on protein turnover is warranted.

Several adult studies have focused on hypocaloric diets, protein content, and exercise training, which may provide some insight for protein recommendations in overweight active individuals. Meckling and Sherfey (75), for example, studied a hypocaloric high-protein diet with and without exercise in a randomized trial with overweight and obese women on weight loss and markers of the metabolic syndrome. While all groups lost weight, the high-protein diet group was better than the low-fat, high-carbohydrate diet group at promoting weight loss and a positive nitrogen balance when the diet alone and diet with exercise interventions were provided. Target carbohydrate to protein ratios for the two diet interventions were 3:1 (low-fat, high-carbohydrate diet) and 1:1 (high-protein diet) (75). In the adult literature, there seems to be increasing support showing improved cardiovascular risk factors with a combined hypocaloric, high protein diet and exercise training intervention (75,89,130). Randomized controlled trials involving children are needed to determine if high protein diets are safe and beneficial for both nonactive and active overweight children.

Very few studies have examined the effect of exercise training on protein turnover in children. One study by Bolster et al. (15) reported decreased protein synthesis and protein breakdown but no effect on net protein turnover in nonoverweight preadolescent boys and girls after a 6 week walking program. Among obese children, Ebbeling & Rodriguez (35) reported slightly different results after 6 weeks of diet intervention followed by 6 weeks of combined diet and walking intervention. At the end of the 6 week diet intervention, the children had a negative energy balance and reduced net protein turnover.

After the walking intervention, net protein turnover and nitrogen balance increased, but still remained below baseline levels. These results suggest that exercise can help minimize protein losses for obese children on a hypocaloric diet (35). To our knowledge, no studies have compared the effects of aerobic training versus resistance training on protein metabolism in overweight children.

In studies that measured protein turnover in young people after a resistance training program, results did not indicate a need for increased protein consumption (54,79,94). In response to a 6-week resistance training program in nonoverweight children, Pikosky et al. (94) showed reduced protein synthesis and protein breakdown. However, increases in strength and mean nitrogen balance were found. Although the underlying mechanisms remain unclear, the authors suggested nutrient partitioning may have contributed to an increased nitrogen balance despite decreased net protein turnover (94). Nutrient partitioning was defined as a state in which nutrients are partitioned differently among metabolic organs and tissues to allow successful execution of a productive function (10,94), such as down-regulating protein turnover in support of growth. Among untrained young males (~22 years), 12 weeks of resistance training resulted in increased net protein balance compared with baseline (54). This suggests that resistance training may result in improved efficiency of protein metabolism (54), and dietary protein requirements are not elevated but may even be slightly reduced. Thus, it is possible that whether overweight young athletes are participating in aerobic- or resistance-based training there is no additional demand to increase protein intake. However, this topic represents an important area for future research.

Protein Recommendations

The estimated average requirements (EAR) for protein in nonoverweight children generally decrease with increasing age. EAR refers to the daily average nutrient intake level to meet nutrient requirements for half of the population, whereas the recommended dietary allowance (RDA) refers to the daily average nutrient intake level to meet requirements for nearly all (97–98%) of the population of healthy individuals for a particular age and gender group (59). In children ages 9–13 years, the protein EAR is 0.76 g/kg/day. For boys and girls ages 14–18 years, the protein EAR are 0.73 g/kg/day and 0.71 g/kg/day, respectively (56). For athletes, it has been reported that adults should aim for protein intake between 1.3–1.8 g/kg/day or closer to 2.0 g/kg/day during intense training (92). There is little information on protein requirements for children participating in regular exercise training. Young gymnasts and soccer players who participated in regular physical activity did not show significant differences in protein turnover compared with nonactive peers (12,13). However, past studies indicate that the RDA of 0.85–0.95 g/kg/day for children (56) is not enough for either active or nonactive children to establish a positive protein bal-

ance (12,14). Among young soccer players, Boisseau and colleagues (14) completed a short term repeated nitrogen balance study with three levels of protein intake: 1.4, 1.2 and 1.0 g of protein per kg of body weight. Using the coefficients of variation for maintenance and protein deposition, EAR and RDA were calculated. Boisseau et al. (14) suggested that adolescents should aim for an EAR of 1.2 g/kg/day and a RDA of 1.4 g/kg/day. Although there are insufficient data to verify that these recommendations are suitable for the overweight young athlete, no current evidence suggests that overweight children would require more or less protein than nonoverweight children. No adult literature has looked at the influence of obesity on dietary protein requirements either. Therefore, this may be an area that requires future attention and reevaluation because of the present high prevalence of obesity.

The timing of protein intake is also important to consider. Protein consumption split between meals throughout the day and after training could help maintain lean tissue development. Research involving adults suggests that the ingestion of protein approximately every 3 hr and early in recovery is ideal for maintaining net protein balance (79). Studies in nonoverweight children also support the benefits of protein consumption after exercise (80,125), however future work examining the timing of protein intake in children and its benefits for overweight children is necessary.

Carbohydrate and Fat Metabolism During Exercise

CHO and fat are the major sources of energy during submaximal exercise. A better understanding of substrate utilization during exercise in overweight children would help provide appropriate recommendations and adjustments to diet when necessary. The main storage form of CHO is glycogen found in the liver and skeletal muscle. At the onset of exercise, most of the CHO used is derived from muscle glycogen, but as the duration of exercise continues the contribution of plasma glucose increases and muscle glycogen decreases (108). Fat used during exercise consists of free fatty acids (FFA) released from adipose tissue triacyglycerol (TAG) and transported in the bloodstream to the skeletal muscle, as well as FFA derived from skeletal muscle TAG (72).

The balance between CHO and fat utilization during exercise is regulated by the intensity of exercise. CHO oxidation rates increase progressively with exercise intensity, while absolute fat oxidation rates increase from low to moderate exercise intensities and decrease at high intensities (18,72). Thus, CHO versus fat utilization may be sport specific depending on the type of exercise performed. Other factors that may influence fuel selection include diet, puberty, sex, cardiorespiratory fitness, duration of exercise, substrate availability and delivery to skeletal muscle, and adiposity (1,47,118). The literature shows that prepubertal children tend to have a preferential use of fat over CHO during low to moderate intensity

exercise compared with postpubertal children and adults (71,99,116). Thus, biological age is an important factor to consider when discussing nutrition for young athletes.

Scientific data on CHO oxidation rates in overweight compared with nonoverweight children during exercise are sparse. McMurray & Hosick (74) reported greater CHO oxidation rates expressed per kg of fat free mass in overweight girls compared with nonoverweight girls at three treadmill speeds (4.0, 5.6 and 8.0 k/h). However, when CHO oxidation rates were adjusted for percent of VO_{2max}, the difference was eliminated. Similarly, CHO oxidation rates adjusted for fat free mass were greater in overweight boys compared with nonoverweight boys (74). There was a trend showing lower CHO oxidation rates in the boys compared with the girls, but no significant difference (74).

Children have different fat oxidation profiles compared with adults, which may be explained by changes during puberty (71,99,116). Fat oxidation rates relative to fat free mass during exercise decreased with pubertal development in nonoverweight (99) and obese boys (132). The exercise intensity that elicited the maximal fat oxidation rate (FATmax) also decreased with puberty (99,132). Only a few studies have examined fat oxidation in overweight or obese children compared with nonoverweight children (25,60,67,74,131). At higher exercise intensities above 40% VO_{2peak}, fat oxidation is lower in obese boys compared with nonobese boys (131). However, other studies have shown that fat oxidation rates adjusted for fat free mass are not influenced by weight status (67,74). Most fat oxidation studies in youth were completed in boys, and to our knowledge only one published study (74) has compared boys and girls, showing no gender differences. In addition, there is little information on fat oxidation profiles in obese girls compared with nonobese girls. Studies have shown that pre- or early-pubertal girls do not have differences in fat oxidation rate between obese and nonobese girls, however in pubertal girls, excess weight resulted in higher fat oxidation rates when adjusted for fat free mass (25,60). Obese girls appeared to oxidize more fat during exercise than nonobese girls to compensate for excess fat availability (25,60). Further research is required to examine sex differences in fat oxidation rate during exercise in young athletes.

To our knowledge, there are no studies that have assessed CHO or fat oxidation in trained overweight children. However, a study in recreationally trained overweight and nonoverweight men produced interesting findings (31), which may provide some insight for overweight young athletes. Trained overweight men ($n = 12$) and trained nonoverweight men ($n = 12$), matched for cardiorespiratory fitness, did not have significant differences in maximal fat oxidation rates during exercise or FATmax. Maximal fat oxidation rate and FATmax were associated with VO_{2max}, but not percent body fat or BMI (31). These findings suggest that physical fitness is an important factor to consider when observing substrate metabolism profiles between individuals, possibly even more so than overweight or obesity status. Among overweight young

athletes and nonoverweight young athletes, it is likely that no differences in substrate oxidation at the same relative exercise intensity would be found if both groups had the same cardiorespiratory fitness.

Overweight athletes may not require different nutritional considerations compared with their nonoverweight peers. However, the composition of diets before exercise, particularly exogenous CHO intake may change the percent contribution of endogenous fat and CHO to total energy expenditure during exercise (26,122). The advantages and disadvantages of CHO-enriched sports drinks are discussed in more detail in the fluid intake and hydration section below.

Carbohydrate Recommendations

The RDA for CHO for adults and children is 130 g/day and is based on the average minimum amount of glucose used by the brain (56). The RDA values do not consider CHO necessary for glycogen replacement after exercise. Petrie et al. suggested that for young athletes at least 50% of total daily energy intake should be from CHO sources (91), which should consist of more complex CHO sources such as whole grains, and less simple CHO sources such as white bread or white rice (44). This falls within the Accepted Macronutrient Distribution Range (AMDR) for children, which is 45–65% of energy (56). For example, if an active male had a daily caloric intake of 2,043–3,263 kcal/day (56) and he consumed 50% of total daily energy from CHO, his average CHO intake would be 255–408 g/day. According to macronutrient intake values summarized from several studies in children, CHO consumption is about 200 g/day in nonoverweight children, 300 g/day in adolescents and up to 500 g/day in young athletes (84,91).

Unfortunately, we do not know for certain if the CHO recommendations listed above would sufficiently maintain muscle glycogen stores among overweight young athletes. Other factors to consider include the mode and intensity of exercise during a training session or sport competition. As the intensity of aerobic exercise increases, CHO utilization is increased (18,72). Regular training at high intensities or for extended periods of aerobic exercise among young athletes could place a greater demand on endogenous CHO stores. It is thought that young children have a poorer glycolytic capacity compared with adults, which may be due to reduced enzymatic content or activity and glycogen storage in the muscle (98,99,122). To this end, the use of sports drinks and/or appropriate postexercise nutrition may be favorable training aids to consider. These items are discussed in more detail below.

There remains a lack of empirical evidence to create distinct nutrition guidelines for overweight young athletes that would be different from nonoverweight athletes. The study by Croci et al. (31) would suggest that different nutrition guidelines for CHO and fat intake are not necessary, assuming similar fitness levels and relative

intensity of physical activity between overweight and nonoverweight children. If the overweight child athlete was to use more CHO compared with fat than his or her nonoverweight teammate, metabolic processes within the body have the capacity to replenish CHO stores via gluconeogenesis. In the presence of CHO availability, another assumption is that the capacity to match CHO utilization with availability is not impaired (i.e., metabolic flexibility) in overweight children (2). With adequate caloric intake, flexibility of the system should allow for nutrient partitioning, although the timing of this is unclear. There is also insufficient knowledge about how and when children replenish their energy stores in recovery.

Dietary Fat Recommendations

The AMDR for total fat is 25–35% of energy for children ages 4–18 years (56). There are no adequate intake or RDA suggestions for total fat intake, because we do not have sufficient data to determine a level of fat intake that would be inadequate or prevent the development of metabolic diseases. However, essential fatty acids, including linoleic and linolenic acid, are important for proper growth and development (56). Among adolescent boys, the adequate intake for linoleic acid and linolenic acid are 16 g/day and 1.6 g/day, respectively. Among adolescent girls, the adequate intake levels suggested for linoleic acid is 11 g/day and for linolenic acid it is 1.1 g/day (56). Other types of fat such as cholesterol and trans fatty acids should be limited in the diet, and saturated fats should make up less than 10% (45). Common weight management strategies for overweight children include choosing more nonfat or low fat dairy products as sources of calcium and protein, such as skim or 1% milk and low fat yogurt (44).

During postprandial conditions, a greater availability of FFA in overweight children may be used as a preferred fuel source during exercise (25,60). Despite greater fat utilization, general dietary fat recommendations should be followed as a potential method to reduce percent body fat if not within the healthy range. In addition, research supports that exercise can help improve lipid profile in children. Acute exercise effectively reduced postprandial TAG concentrations on the following day in nonoverweight boys and girls (120,123). There is no evidence to indicate that adjusting dietary fat intake would be beneficial for young athletes and enhance sport performance in any way.

If optimizing fat oxidation during training is a goal for the overweight athlete, special attention may also be given to macronutrient profile over time. However, more research is required to adapt and translate available findings to children. Research in obese adults found that a low CHO, high fat diet over 8 weeks shifted fuel utilization toward greater fat oxidation during exercise, while the high CHO, low fat diet intervention did not (17). Although interesting, the low CHO diet (35% protein, 61% fat, 4% CHO) is outside of the AMDR ranges

for both fat and CHO, and we would not recommend such extreme macronutrient composition changes to the diet of children. Another study involving obese adults reported that a low glycemic diet versus a high glycemic diet for 8 weeks also improved fat oxidation (114). This diet intervention should also be carefully reviewed and studied in children under safe conditions to determine its appropriateness. Future work with overweight children in this area is necessary.

Postexercise Nutrition

Postexercise nutrition is essential for replenishing nutrients, promoting recovery and optimizing exercise training benefits. It is well accepted that protein consumption in early recovery helps fuel muscle protein synthesis (20,64,93). Most of the research is in adults, but recent studies in children also showed improved whole body protein balance with postexercise protein intake (80,125). In nonoverweight active children, whole body protein balance was measured during recovery and after three postexercise beverages were provided (control, low protein [~0.18 g/kg body weight] and high protein [~0.32 g/kg body weight]). Whole body protein balance was positive for all conditions at 9 hr after exercise, while only the high protein beverage helped young children maintain a positive whole body protein balance for 24 hr postexercise (80). The protein source used in the study was skim milk, which is thought to maintain protein balance better than a CHO-enriched sports drink or water in nonoverweight children (125). Therefore, the consumption of lean protein options (lower in saturated fats) is preferred. We do not suspect that the macronutrient composition of a postexercise snack should be different between overweight and nonoverweight young athletes.

After exercise, adequate fluids, electrolytes, and CHO are also important to replace muscle glycogen and ensure rapid recovery. CHO intake immediately after exercise is recommended because glycogen stores are replenished more efficiently during the first hour after exercise (23). Refueling snacks that contain small amounts of protein also help facilitate muscle glycogen storage (23). The Joint Position Statement by the American Dietetic Association, Dieticians of Canada and the American College of Sports Medicine suggests CHO intake of approximately 1.0–1.5 g/kg body weight in the first 30 min of recovery and again every 2 hr for 4–6 hr (107). How applicable these recommendations are for children has not been well addressed by research. This may be a good target for some children, as the recommendation matches with data showing total CHO oxidation in children to be about 1.0–1.5 g per kg of body weight per hour during heavy exercise (100). Among adults, research indicates that high glycemic CHO sources were better than low glycemic CHO sources for increasing muscle glycogen levels at 24 hr postexercise (22). However, postexercise CHO should be considered along with the overall diet, as isocaloric CHO versus CHO plus protein

and fat resulted in similar glycogen synthesis rates in adults (21,107,110). Given that overweight children may have weight management goals and should avoid over consumption of nutrient-poor calories, we recommend a nutrient-dense snack instead of simple sugars. Whole grains and fruits and vegetables are good sources of CHO and other important nutrients such as vitamins, minerals and dietary fiber (76). Other than nonfat or 1% milk or yogurt, other postexercise options for the early recovery period could include nutrient-dense foods such as a whole-wheat peanut butter sandwich, fruit and vegetables, or assorted nuts.

Micronutrient Recommendations

Iron

Iron is an important micronutrient to monitor for young athletes, especially during growth and development. It is a critical component of hemoglobin that aids in the transportation of oxygen and carbon dioxide in the blood. Other roles of iron include extracting oxygen from hemoglobin in muscle tissue and acting as an antioxidant (106). Iron is stored as ferritin and is circulated as transferrin. It is rare for athletes to develop anemia, but reduced serum ferritin levels is common in young athletes in various sport disciplines (29,86). Iron stores are influenced by dietary intake, iron loss and absorption. Adequate protein intake enhances iron absorption, while diets high in CHO and fats could inhibit iron absorption (91). Iron stores can also be affected by changes in muscle mass and nutrition, as well as menstruation in females (109).

Iron deficiency can impair muscle metabolism through hindered oxygen transport to skeletal muscle and affect cognitive function (19,51). Female athletes are more likely to have iron deficiency (86), but sport involvement and training can lead to greater iron losses in both young males and females (29,34,63,87). Iron deficiency seems to be increased in overweight children based on data from the National Health and Nutrition Examination Survey III (1988–1994) (83). Iron deficiency increased as BMI increased, and was particularly common in overweight children ages 12–16 years (83). To the best of our knowledge, no one has assessed whether there is a greater prevalence of iron deficiency in overweight child or adult athletes. Screening for iron deficiency in overweight children may be something that requires greater attention, especially if the children are involved with regular training.

In boys and girls ages 9–13 years, the RDA for iron is 8 mg/day. In boys and girls ages 14–18 years, the RDA is 11 mg/day and 15 mg/day, respectively (57). Caution should be taken when providing iron supplements to young athletes. Further discussion about iron supplementation may be found elsewhere (106). Potential risks of iron overload, when excess iron is stored in the organs of the body, include direct erosion and irritation of the gastrointestinal mucosa, damage of lipid membranes,

proteins or DNA, inflammation or supporting the growth of pathogens (111). Although iron supplements may be beneficial if dietary intake of iron is poor, young athletes do not require more than the RDA. Additional iron does not appear to provide any performance benefits in young athletes (106,124).

Calcium and Vitamin D

Calcium intake is critical for children and adolescents for obtaining an optimal peak bone mass. Vitamin D functions to enhance calcium absorption in the gut, maintain normal mineralization of calcium and phosphate in the bone and has a vital role in bone growth and bone remodeling (30). It is estimated that about 90% of bone mineral density is acquired by age 20, with a large proportion of bone mineral density occurring at the time of puberty (4,46). Inadequate calcium and vitamin D intake and low bone mineral density may increase the risk of bone fractures and the development of osteoporosis later in life (48,49,95,102).

Most adolescents, including both nonoverweight and overweight children, are not meeting the recommended guidelines for calcium intake. In the U.S. from 1999 to 2004, only 30% population obtained the recommended amount of calcium in participants 2 years and older (88). Adequate calcium and vitamin D intake is particularly important in overweight children because of their increased risk for fractures (119), which may be explained by a lower bone mineral content for body weight (50). Goulding and colleagues (50) found that bone mass (total body mineral content and bone area) relative to body weight was reported to be 2.5–10.1% less than predicted values in overweight and obese children compared with nonoverweight children. Increasing physical activity is a way to counteract the potential lower bone mineral content in overweight children and reduce the risk of fractures (4,97). Improved strategies to encourage children and their parents to meet the recommended guidelines are crucial.

Calcium intake has major influences on calcium retention in adolescents. The RDAs for calcium and vitamin D for children ages 9–18 years are 1300 mg/day and 5 ug/day, respectively (57). Hill et al. (55) found that overweight and obese adolescents had greater calcium retention with increasing calcium intake compared with nonoverweight adolescents, but found no effect of BMI on calcium retention at low calcium intakes. Future studies are needed to confirm if higher calcium intake leads to higher bone mineral accretion in overweight children compared with nonoverweight children. To date, there are no studies that have examined calcium intake in overweight adults or child athletes compared with nonoverweight athletes.

Fluid Intake and Hydration

Dehydration is likely to occur in young athletes during or after prolonged and intermittent exercise, especially when fluid loss through sweat is not matched by fluid intake. Fluid and electrolyte loss may vary between athletes, and is affected by temperature and humidity of the environment, as well as the duration and intensity of training sessions (40,76). Children produce more metabolic heat per kg of body weight during exercise than adults (7), which is attributed to a greater surface area to body weight ratio in children versus adults (27). Greater heat stress is more likely to occur in children because they absorb heat from the environment more readily and have a lower sweating capacity than adults (7,27,41). With dehydration, core temperature rises faster in children compared with adults (8).

Voluntary dehydration, defined as inadequate fluid intake even when fluid is offered ad libitum during exercise, commonly occurs in children (8). Since young athletes tend to start training sessions hypohydrated, particular attention should be given to hydration status at the start of exercise, during and after training (76). Based on recommendations published by the Institute of Medicine, water consumption in boys and girls ages 9–13 years should be 2.4 L/day (~8 cups) and 2.1 L/day (~7 cups), respectively, whereas boys and girls ages 14–18 years should have 3.3 L/day (~11 cups) and 2.3 L/day (~8 cups) (58). A summary of sweat rates in young athletes reported that exercise increased fluid requirements above baseline by 0.5–1.0 L/day (91). Among overweight children, thermoregulatory responses and sweating volume are presumed to be similar to nonoverweight children (69,112). Therefore, we believe hydration recommendations should be similar for overweight and nonoverweight athletes.

Water is usually the best option for hydration for young athletes (28). Sports drinks are popular among adult athletes; however, their reputation for sport performance of young athletes is controversial. Due to marketing schemes that emphasize optimal athletic performance and the need to replenish fluid loss and electrolytes, sports drinks are often consumed by children when they are commonly unnecessary (28). Careful consideration is required to assess the pros and cons of sports drink consumption for each individual, especially overweight young athletes. Although a CHO-enriched drink (glucose + fructose) ingested before exercise prolonged time to exhaustion (~40%) compared with the water and glucose alone trials, it resulted in the sparing of endogenous fuels in nonoverweight children (101). With sports drink consumption, boys compared with men also preferentially use more exogenous CHO than endogenous CHO during cycling exercise (122). Among obese boys, CHO ingestion before 60 min of exercise decreased endogenous fat utilization by over 50% (25). As a result, for overweight young athletes trying to maintain or reduce weight, sports drinks would increase caloric intake and lead to poorer endogenous fuel metabolism.

On the contrary, sports drinks can provide several benefits when consumed appropriately, such as during prolonged exercise (>1.5–2 hr) or on training or tournament days that include frequent bouts of high intensity

exercise with short recovery periods (78). Dougherty et al. (32) also reported improved performance of basketball skills in young boys with a 6% CHO drink with electrolytes compared with a placebo drink. In general, sports drinks consist of 6–8% CHO with mainly glucose, sucrose or fructose and the electrolytes sodium, potassium and magnesium. Benefits of this drink composition include improving hydration and fluid absorption, maintaining blood glucose and replenishing electrolytes lost through sweating (28,78). The flavoring of sports drink with sodium and chloride encourages fluid intake in children and helps prevent dehydration (129). In addition, sports drinks are beneficial because greater sodium and chloride concentrations in the sweat of children compared with adults (77) could increase the risk of hyponatremia, particularly when combined with sweating rates and excessive sodium-free fluid consumption (78). Unfortunately, very little is known about hyponatremia and electrolytes lost during exercise in children. Generally, water should be promoted as the primary source of hydration but can be combined with sports drink ingestion if rapid replenishment of CHO, fluids, and electrolytes are required. The main caveat for overweight young athletes is the excess caloric intake, which may be insignificant if weight management goals are still achieved.

Potential Barriers to Sport Participation

The reality for many children is that excess adiposity creates stigmatisms that can have negative psychosocial consequences. Some of these psychosocial consequences include weight bias and body image disturbance, which have been linked to low self-esteem and depression (53,96,121). Overweight children may be at a greater risk for low self-esteem (121). The link between obesity and low self-esteem is likely due to social factors related to weight status such as teasing from peers and weight-related criticism by parents that affect self-esteem (53,96). Weight stigmatization creates bias and social marginalization, which results in peers viewing overweight children as different and undesirable (104,117). As a result of weight stigmatization and teasing, unhealthy weight control behaviors, such as dieting, fasting, binging and the use of laxatives and diuretics are more common in overweight adolescents than nonoverweight adolescents (16,85).

There is insufficient data to determine how psychosocial consequences of obesity directly affect sport participation in overweight children. We do not know if overweight athletes are as susceptible to low self-esteem and depression as nonactive overweight children. For overweight children already involved with sports, there may be less social marginalization. Strauss and Pollack (117) found that even though overweight children were more likely to be socially isolated than nonoverweight children, decreased television time, increased levels of sport participation and increased participation in school clubs led to more friendship nominations (i.e., less social marginalization) among overweight and nonoverweight

children. Given the many benefits of sport participation, we should continue to examine and discuss strategies that improve psychosocial and physical health in overweight young athletes.

Summary

Due to a high prevalence of childhood obesity, a greater number of young athletes may be overweight. Certain sports may actually select overweight children based on their large size. Pediatric obesity treatments and weight management programs advocate better healthy eating habits and increased physical activity. For overweight children, sport participation is a great outlet and environment for increasing energy expenditure, especially if their body weight does not lead to a disadvantage compared with other children. Appropriate nutritional guidelines are critical for optimal growth and health, as well as training and performance. Yet, there remains a paucity of research concerning nutrition for overweight young athletes. To attain adequate energy sources for growth and maturation while participating in regular training sessions can be challenging for children, but even more so if there are additional energy restrictions to meet weight loss goals. Weight management may result in a hypocaloric diet and/or a negative nitrogen balance in overweight young athletes. Currently, there is limited research to determine if more or less protein and CHO should be recommended in overweight young athletes compared with nonoverweight young athletes. Fat intake, micronutrients, postexercise nutrition and hydration are also important areas to consider. In addition, overweight children may experience psychosocial barriers that could contribute to unhealthy eating behaviors. The identification and acknowledgment of gaps in knowledge and challenges will help develop recommendations for overweight youth that desire to train and compete in sport. Opening discussions about nutrition for the overweight athlete will hopefully result in future research and solutions that will encourage more sport participation, eliminate barriers, and optimize health and athletic performance for these children.

References

1. Aucouturier J, Baker JS, Duché P. Fat and carbohydrate metabolism during submaximal exercise in children. *Sports Med.* 2008; 38(3):213–238. PubMed doi:10.2165/00007256-200838030-00003

2. Aucouturier J, Duché P, Timmons BW. Metabolic flexibility and obesity in children and youth. *Obes Rev.* 2011; 12(5):e44–e53. PubMed doi:10.1111/j.1467-789X.2010.00812.x

3. Aull JL, Rowe DA, Hickner RC, Malinauskas BM, Mahar MT. Energy expenditure of obese, overweight, and normal weight females during lifestyle physical activities. *Int J Pediatr Obes.* 2008; 3(3):177–185. PubMed doi:10.1080/17477160701874844

4. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. *J Bone Miner Res.* 1999; 14(10):1672–1679. PubMed doi:10.1359/jbmr.1999.14.10.1672

5. Barlow SE, Dietz WH. Obesity Evaluation and Treatment: Expert Committee Recommendations. *Pediatrics.* 1998; 102(3):e29–e29. PubMed doi:10.1542/peds.102.3.e29

6. Bar-Or O. Nutritional considerations for the child athlete. *Can J Appl Physiol.* 2001; 26(Suppl.):S186–S191. PubMed doi:10.1139/h2001-053

7. Bar-Or O. *Temperature regulation during exercise in children and adolescents*. In: Gisolfi CV and Lamb DR, editors. Perspectives in Exercise Science and Sports Medicince.Vol. 2. Youth, Exercise and Sport. Indianapolis, IN: Benchmark Press; 1989. p. 335-367.

8. Bar-Or O, Dotan R, Inbar O, Rotshtein A, Zonder H. Voluntary hypohydration in 10- to 12-year-old boys. *J Appl Physiol.* 1980; 48(1):104–108. PubMed

9. Bar-Or O, Unnithan VB. Nutritional requirements of young soccer players. *J Sports Sci.* 1994; 12(Spec No):S39–S42. PubMed

10. Beermann DH. Coordination of nutrient use by peripheral and visceral tissues. *J Nutr.* 1994; 124(8, Suppl.):1392S. PubMed

11. Blaak EE, Westerterp KR, Bar-Or O, Wouters LJ, Saris WH. Total energy expenditure and spontaneous activity in relation to training in obese boys. *Am J Clin Nutr.* 1992; 55(4):777–782. PubMed

12. Boisseau N, Creff CL, Loyens M, Poortmans J. Protein intake and nitrogen balance in male non-active adolescents and soccer players. *Eur J Appl Physiol.* 2002; 88(3):288–293. PubMed doi:10.1007/s00421-002-0726-x

13. Boisseau N, Persaud C, Jackson AA, Poortmans JR. Training does not affect protein turnover in pre- and early pubertal female gymnasts. *Eur J Appl Physiol.* 2005;94(3):262–7.

14. Boisseau N, Vermorel M, Rance M, Duché P, Patureau-Mirand P. Protein requirements in male adolescent soccer players. *Eur J Appl Physiol.* 2007; 100(1):27–33. PubMed doi:10.1007/s00421-007-0400-4

15. Bolster DR, Pikosky MA, McCarthy LM, Rodriguez NR. Exercise Affects Protein Utilization in Healthy Children. *J Nutr.* 2001; 131(10):2659–2663. PubMed

16. Boutelle K, Neumark-Sztainer D, Story M, Resnick M. Weight control behaviors among obese, overweight, and nonoverweight adolescents. *J Pediatr Psychol.* 2002; 27(6):531–540. PubMed doi:10.1093/jpepsy/27.6.531

17. Brinkworth GD, Noakes M, Clifton PM, Buckley JD. Effects of a low carbohydrate weight loss diet on exercise capacity and tolerance in obese subjects. *Obesity (Silver Spring).* 2009; 17(10):1916–1923. PubMed doi:10.1038/oby.2009.134

18. Brooks GA, Mercier J. Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. *J Appl Physiol.* 1994; 76(6):2253–2261. PubMed

19. Bruner AB, Joffe A, Duggan AK, Casella JF, Brandt J. Randomised study of cognitive effects of iron supplementation in non-anaemic iron-deficient adolescent girls. *Lancet.* 1996; 348(9033):992–996. PubMed doi:10.1016/S0140-6736(96)02341-0

20. Burd NA, Tang JE, Moore DR, Phillips SM. Exercise training and protein metabolism: influences of contraction, protein intake, and sex-based differences. *J Appl Physiol.* 2009; 106(5):1692–1701. PubMed doi:10.1152/japplphysiol.91351.2008

21. Burke LM, Collier GR, Beasley SK, et al. Effect of coingestion of fat and protein with carbohydrate feedings on muscle glycogen storage. *J Appl Physiol.* 1995; 78(6):2187–2192. PubMed

22. Burke LM, Collier GR, Hargreaves M. Muscle glycogen storage after prolonged exercise: effect of the glycemic index of carbohydrate feedings. *J Appl Physiol.* 1993; 75(2):1019–1023. PubMed

23. Burke LM, Kiens B, Ivy JL. Carbohydrates and fat for training and recovery. *J Sports Sci.* 2004; 22(1):15–30. PubMed doi:10.1080/0264041031000140527

24. Choate N, Forster C, Almquist J, Olsen C, Poth M. The Prevalence of Overweight in Participants in High School Extramural Sports. *J Adolesc Health.* 2007; 40(3):283–285. PubMed doi:10.1016/j.jadohealth.2006.09.014

25. Chu L, Riddell MC, Schneiderman JE, McCrindle BW, Hamilton JK. The effect of puberty on fat oxidation rates during exercise in overweight and normal-weight girls. *J Appl Physiol.* 2014; 116(1):76–82. PubMed doi:10.1152/japplphysiol.00888.2013

26. Chu L, Riddell MC, Takken T, Timmons BW. Carbohydrate intake reduces fat oxidation during exercise in obese boys. *Eur J Appl Physiol.* 2011; 111(12):3135–3141. PubMed doi:10.1007/s00421-011-1940-1

27. Climatic heat stress and the exercising child and adolescent. American Academy of Pediatrics. Committee on Sports Medicine and Fitness. *Pediatrics.* 2000; 106(1 Pt 1):158–159. PubMed

28. Committee on Nutrition and the Council on Sports Medicine and Fitness. Sports drinks and energy drinks for children and adolescents: are they appropriate? *Pediatrics.* 2011; 127(6):1182–1189. PubMed doi:10.1542/peds.2011-0965

29. Constantini NW, Eliakim A, Zigel L, Yaaron M, Falk B. Iron status of highly active adolescents: evidence of depleted iron stores in gymnasts. *Int J Sport Nutr Exerc Metab.* 2000; 10(1):62–70. PubMed

30. Cranney A, Horsley T, O'Donnell S, et al. Effectiveness and safety of vitamin D in relation to bone health. *Evid Rep Technol Assess.* 2007; (158):1–235. PubMed

31. Croci I, Hickman IJ, Wood RE, Borrani F, Macdonald GA, Byrne NM. Fat oxidation over a range of exercise intensities: fitness versus fatness. *Appl Physiol Nutr Metab.* 2014; 39(12):1352–1359. PubMed doi:10.1139/apnm-2014-0144

32. Dougherty KA, Baker LB, Chow M, Kenney WL. Two percent dehydration impairs and six percent carbohydrate drink improves boys basketball skills. *Med Sci Sports Exerc.* 2006; 38(9):1650–1658. PubMed doi:10.1249/01.mss.0000227640.60736.8e

33. Drenowatz C, Steiner RP, Brandstetter S, et al. Organized Sports, Overweight, and Physical Fitness in Primary School Children in Germany. *J Obes.* 2013;2013:e935245.

34. Dubnov G, Constantini NW. Prevalence of iron depletion and anemia in top-level basketball players. *Int J Sport Nutr Exerc Metab.* 2004; 14(1):30–37. PubMed

35. Ebbeling CB, Rodriguez NR. Effects of exercise combined with diet therapy on protein utilization in obese children. *Med Sci Sports Exerc.* 1999; 31(3):378–385. PubMed doi:10.1097/00005768-199903000-00005

36. Ebbeling CB, Rodriguez NR. Effects of reduced energy intake on protein utilization in obese children. *Metabolism.* 1998; 47(12):1434–1439. PubMed doi:10.1016/S0026-0495(98)90066-X

37. Eisenmann JC. Aerobic fitness, fatness and the metabolic syndrome in children and adolescents. *Acta Paediatr. 1992* 2007;96(12):1723–9.

38. Elkins WL, Cohen DA, Koralewicz LM, Taylor SN. After school activities, overweight, and obesity among inner city youth. *J Adolesc.* 2004; 27(2):181–189. PubMed doi:10.1016/j.adolescence.2003.10.010

39. Ervin RB, Fryar CD, Wang C-Y, Miller IM, Ogden CL. Strength and body weight in US children and adolescents. *Pediatrics.* 2014; 134(3):e782–e789. PubMed doi:10.1542/peds.2014-0794

40. Falk B. Effects of thermal stress during rest and exercise in the paediatric population. *Sports Med.* 1998; 25(4):221–240. PubMed doi:10.2165/00007256-199825040-00002

41. Falk B, Bar-Or O, MacDougall JD. Thermoregulatory responses of pre-, mid-, and late-pubertal boys to exercise in dry heat. *Med Sci Sports Exerc.* 1992; 24(6):688–694. PubMed doi:10.1249/00005768-199206000-00011

42. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *JAMA.* 2010; 303(3):235–241. PubMed doi:10.1001/jama.2009.2014

43. Frost G, Bar-Or O, Dowling J, Dyson K. Explaining differences in the metabolic cost and efficiency of treadmill locomotion in children. *J Sports Sci.* 2002; 20(6):451–461. PubMed doi:10.1080/02640410252925125

44. Gidding SS, Dennison BA, Birch LL, et al. Dietary Recommendations for Children and Adolescents: A Guide for Practitioners. *Pediatrics.* 2006; 117(2):544–559. PubMed doi:10.1542/peds.2005-2374

45. Gidding SS, Dennison BA, Birch LL, et al. Dietary Recommendations for Children and Adolescents A Guide for Practitioners: Consensus Statement From the American Heart Association. *Circulation.* 2005; 112(13):2061–2075. PubMed doi:10.1161/CIRCULATIONAHA.105.169251

46. Glastre C, Braillon P, David L, Cochat P, Meunier PJ, Delmas PD. Measurement of bone mineral content of the lumbar spine by dual energy x-ray absorptiometry in normal children: correlations with growth parameters. *J Clin Endocrinol Metab.* 1990; 70(5):1330–1333. PubMed doi:10.1210/jcem-70-5-1330

47. Goodpaster BH, Wolfe RR, Kelley DE. Effects of obesity on substrate utilization during exercise. *Obes Res.* 2002; 10(7):575–584. PubMed doi:10.1038/oby.2002.78

48. Goulding A, Cannan R, Williams SM, Gold EJ, Taylor RW, Lewis-Barned NJ. Bone mineral density in girls with forearm fractures. *J Bone Miner Res.* 1998; 13(1):143–148. PubMed doi:10.1359/jbmr.1998.13.1.143

49. Goulding A, Jones IE, Taylor RW, Williams SM, Manning PJ. Bone mineral density and body composition in boys with distal forearm fractures: a dual-energy x-ray absorptiometry study. *J Pediatr.* 2001; 139(4):509–515. PubMed doi:10.1067/mpd.2001.116297

50. Goulding A, Taylor RW, Jones IE, McAuley KA, Manning PJ, Williams SM. Overweight and obese children have low bone mass and area for their weight. *Int J Obes Relat Metab Disord.* 2000; 24(5):627–632. PubMed doi:10.1038/sj.ijo.0801207

51. Grantham-McGregor S, Ani C. A review of studies on the effect of iron deficiency on cognitive development in children. *J Nutr.* 2001;131(2S-2):649S – 666S; discussion 666S – 668S.

52. Harrell JS, McMurray RG, Baggett CD, Pennell ML, Pearce PF, Bangdiwala SI. Energy costs of physical activities in children and adolescents. *Med Sci Sports Exerc.* 2005; 37(2):329–336. PubMed doi:10.1249/01.MSS.0000153115.33762.3F

53. Harriger JA, Thompson JK. Psychological consequences of obesity: weight bias and body image in overweight and obese youth. *Int Rev Psychiatry.* 2012; 24(3):247–253. PubMed doi:10.3109/09540261.2012.678817

54. Hartman JW, Moore DR, Phillips SM. Resistance training reduces whole-body protein turnover and improves net protein retention in untrained young males. *Appl Physiol Nutr Metab.* 2006; 31(5):557–564. PubMed doi:10.1139/h06-031

55. Hill KM, Braun MM, Egan KA, et al. Obesity augments calcium-induced increases in skeletal calcium retention in adolescents. *J Clin Endocrinol Metab.* 2011; 96(7):2171–2177. PubMed doi:10.1210/jc.2010-2709

56. Institute of Medicine of National Academies. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients).* Washington, D.C.: The National Academies Press; 2005.

57. Institute of Medicine of National Academies. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.* Washington, D.C.: The National Academies Press; 2001.

58. Institute of Medicine of National Academies. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate.* Washington, D.C.: The National Academies Press; 2005.

59. Institute of Medicine of National Academies. *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements.* Washington, D.C.: The National Academies Press; 2006.

60. Jabbour G, O'Loughlin J, Sabiston C, Tremblay A, Mathieu M-E. Increased lipid oxidation during exercise in obese pubertal girls: a QUALITY study. *Obesity (Silver Spring).* 2014; 22(5):E85–E90. PubMed doi:10.1002/oby.20611

61. Janssen I, Katzmarzyk PT, Ross R. Body mass index, waist circumference, and health risk: evidence in support of current National Institutes of Health guidelines. *Arch Intern Med.* 2002; 162(18):2074–2079. PubMed doi:10.1001/archinte.162.18.2074

62. Janssen I, Shields M, Craig CL, Tremblay MS. Prevalence and secular changes in abdominal obesity in Canadian adolescents and adults, 1981 to 2007–2009. *Obes Rev.* 2011; 12(6):397–405. PubMed doi:10.1111/j.1467-789X.2010.00815.x

63. Koehler K, Braun H, Achtzehn S, et al. Iron status in elite young athletes: gender-dependent influences of diet and exercise. *Eur J Appl Physiol.* 2012; 112(2):513–523. PubMed doi:10.1007/s00421-011-2002-4

64. Koopman R, Saris WHM, Wagenmakers AJM, van Loon LJC. Nutritional interventions to promote post-exercise muscle protein synthesis. *Sports Med.* 2007; 37(10):895–906. PubMed doi:10.2165/00007256-200737100-00005

65. Krahenbuhl GS, Williams TJ. Running economy: changes with age during childhood and adolescence. *Med Sci Sports Exerc.* 1992; 24(4):462–466. PubMed doi:10.1249/00005768-199204000-00012

66. Lazzer S, Boirie Y, Bitar A, et al. Assessment of energy expenditure associated with physical activities in free-living obese and nonobese adolescents. *Am J Clin Nutr.* 2003; 78(3):471–479. PubMed

67. Lazzer S, Busti C, Agosti F, De Col A, Pozzo R, Sartorio A. Optimizing fat oxidation through exercise in severely obese Caucasian adolescents. *Clin Endocrinol (Oxf).* 2007; 67(4):582–588. PubMed

68. Lee S, Kuk JL, Katzmarzyk PT, Blair SN, Church TS, Ross R. Cardiorespiratory fitness attenuates metabolic risk independent of abdominal subcutaneous and visceral fat in men. *Diabetes Care.* 2005; 28(4):895–901. PubMed doi:10.2337/diacare.28.4.895

69. Leites GT, Sehl PL, Cunha GDS, Detoni Filho A, Meyer F. Responses of obese and lean girls exercising under heat and thermoneutral conditions. *J Pediatr.* 2013; 162(5):1054–1060. PubMed doi:10.1016/j.jpeds.2012.10.047

70. MacDougall J, Roche P, Bar-Or O, Moroz J. Maximal Aerobic Capacity of Canadian Schoolchildren: Prediction Based on Age-Related Oxygen Cost of Running. *Int J Sports Med.* 1983; 04(03):194–198. PubMed doi:10.1055/s-2008-1026034

71. Martinez LR, Haymes EM. Substrate utilization during treadmill running in prepubertal girls and women. *Med Sci Sports Exerc.* 1992; 24(9):975–983. PubMed doi:10.1249/00005768-199209000-00005

72. Martin WH, Klein S. Use of endogenous carbohydrate and fat as fuels during exercise. *Proc Nutr Soc.* 1998; 57(01):49–54. PubMed doi:10.1079/PNS19980008

73. McCarthy HD, Cole TJ, Fry T, Jebb SA, Prentice AM. Body fat reference curves for children. *Int J Obes.* 2006; 30(4):598–602. PubMed doi:10.1038/sj.ijo.0803232

74. McMurray RG, Hosick PA. The interaction of obesity and puberty on substrate utilization during exercise: a gender comparison. *Pediatr Exerc Sci.* 2011; 23(3):411–431. PubMed

75. Meckling KA, Sherfey R. A randomized trial of a hypocaloric high-protein diet, with and without exercise, on weight loss, fitness, and markers of the Metabolic Syndrome in overweight and obese women. *Appl Physiol Nutr Metab Physiol.* 2007; 32(4):743–752. PubMed doi:10.1139/H07-059

76. Meyer F, O'Connor H, Shirreffs SM. Nutrition for the young athlete. *J Sports Sci.* 2007;25(sup1):S73–82. doi:10.1080/02640410701607338

77. Meyer F, Bar-Or O, MacDougall D, Heigenhauser GJ. Sweat electrolyte loss during exercise in the heat: effects of gender and maturation. *Med Sci Sports Exerc.* 1992; 24(7):776–781. PubMed doi:10.1249/00005768-199207000-00007

78. Meyer F, Timmons BW. The Young Athlete. In: R Maughan, editor. *The Encyclopedia of Sports Medicine.* Chichester, UK: John Wiley & Sons Ltd; 2013. p. 359–368. doi:10.1002/9781118692318.ch29

79. Moore DR, Bel NCD, Nizi KI, et al. Resistance Training Reduces Fasted- and Fed-State Leucine Turnover and Increases Dietary Nitrogen Retention in Previously Untrained Young Men. *J Nutr.* 2007; 137(4):985–991. PubMed

80. Moore DR, Volterman KA, Obeid J, Offord EA, Timmons BW. Postexercise protein ingestion increases whole body net protein balance in healthy children. *J Appl Physiol.* 2014; 117(12):1493–1501. PubMed doi:10.1152/japplphysiol.00224.2014

81. Morgan DW, Tseh W, Caputo JL, et al. Longitudinal profiles of oxygen uptake during treadmill walking in able-bodied children: the locomotion energy and growth study. *Gait Posture.* 2002; 15(3):230–235. PubMed doi:10.1016/S0966-6362(01)00160-6

82. Nahhas RW, Sherwood RJ, Chumlea WC, Towne B, Duren DL. Predicting the timing of maturational spurts in skeletal age. *Am J Phys Anthropol.* 2013; 150(1):68–75. PubMed doi:10.1002/ajpa.22142

83. Nead KG, Halterman JS, Kaczorowski JM, Auinger P, Weitzman M. Overweight children and adolescents: a risk group for iron deficiency. *Pediatrics.* 2004; 114(1):104–108. PubMed doi:10.1542/peds.114.1.104

84. Nemet D, Eliakim A. Pediatric sports nutrition: an update. *Curr Opin Clin Nutr Metab Care.* 2009; 12(3):304–309. PubMed doi:10.1097/MCO.0b013e32832a215b

85. Neumark-Sztainer D, Story M, Hannan PJ, Perry CL, Irving LM. Weight-related concerns and behaviors among overweight and nonoverweight adolescents: implications for preventing weight-related disorders. *Arch Pediatr Adolesc Med.* 2002; 156(2):171–178. PubMed doi:10.1001/archpedi.156.2.171

86. Nickerson HJ, Holubets MC, Weiler BR, Haas RG, Schwartz S, Ellefson ME. Causes of iron deficiency in adolescent athletes. *J Pediatr.* 1989; 114(4 Pt 1):657–663. PubMed doi:10.1016/S0022-3476(89)80717-6

87. Nickerson HJ, Holubets M, Tripp AD, Pierce WE. Decreased iron stores in high school female runners. *Am J Dis Child. 1960* 1985;139(11):1115–9.

88. Nicklas TA, O'Neil CE, Fulgoni VL. The role of dairy in meeting the recommendations for shortfall nutrients in the

American diet. *J Am Coll Nutr.* 2009; 28(Suppl. 1):73S–81S. PubMed doi:10.1080/07315724.2009.10719807

89. Noakes M, Keogh JB, Foster PR, Clifton PM. Effect of an energy-restricted, high-protein, low-fat diet relative to a conventional high-carbohydrate, low-fat diet on weight loss, body composition, nutritional status, and markers of cardiovascular health in obese women. *Am J Clin Nutr.* 2005; 81(6):1298–1306. PubMed

90. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA.* 2014; 311(8):806–814. PubMed doi:10.1001/jama.2014.732

91. Petrie HJ, Stover EA, Horswill CA. Nutritional concerns for the child and adolescent competitor. *Nutrition.* 2004; 20(7–8):620–631. PubMed doi:10.1016/j.nut.2004.04.002

92. Phillips SM, Van Loon LJC. Dietary protein for athletes: From requirements to optimum adaptation. *J Sports Sci.* 2011;29(sup1):S29–38.

93. Phillips SM, Moore DR, Tang JE. A critical examination of dietary protein requirements, benefits, and excesses in athletes. *Int J Sport Nutr Exerc Metab.* 2007; 17(Suppl.):S58–S76. PubMed

94. Pikosky M, Faigenbaum A, Westcott W, Rodriguez N. Effects of resistance training on protein utilization in healthy children. *Med Sci Sports Exerc.* 2002; 34(5):820–827. PubMed doi:10.1097/00005768-200205000-00015

95. Pires LAS, de Souza ACA, Laitano O, Meyer F. [Bone mineral density, milk intake and physical activity in boys who suffered forearm fractures]. *J Pediatr (Rio J).* 2005; 81(4):332–336. PubMed doi:10.2223/JPED.1370

96. Puhl RM, Latner JD. Stigma, obesity, and the health of the nation's children. *Psychol Bull.* 2007; 133(4):557–580. PubMed doi:10.1037/0033-2909.133.4.557

97. Qu X, Zhang X, Zhai Z, et al. Association between physical activity and risk of fracture. *J Bone Miner Res.* 2014; 29(1):202–211. PubMed doi:10.1002/jbmr.2019

98. Riddell MC. The endocrine response and substrate utilization during exercise in children and adolescents. *J Appl Physiol.* 2008; 105(2):725–733. PubMed doi:10.1152/japplphysiol.00031.2008

99. Riddell MC, Jamnik VK, Iscoe KE, Timmons BW, Gledhill N. Fat oxidation rate and the exercise intensity that elicits maximal fat oxidation decreases with pubertal status in young male subjects. *J Appl Physiol.* 2008; 105(2):742–748. PubMed doi:10.1152/japplphysiol.01256.2007

100. Riddell MC, Bar-Or O, Schwarcz HP, Heigenhauser GJ. Substrate utilization in boys during exercise with [13C]-glucose ingestion. *Eur J Appl Physiol.* 2000;83(4-5):441–8.

101. Riddell MC, Bar-Or O, Wilk B, Parolin ML, Heigenhauser GJ. Substrate utilization during exercise with glucose and glucose plus fructose ingestion in boys ages 10–14 yr. *J Appl Physiol.* 2001; 90(3):903–911. PubMed

102. Rizzoli R, Bianchi ML, Garabédian M, McKay HA, Moreno LA. Maximizing bone mineral mass gain during growth for the prevention of fractures in the adolescents and the elderly. *Bone.* 2010; 46(2):294–305. PubMed doi:10.1016/j.bone.2009.10.005

103. Roberts KC, Shields M, de Groh M, Aziz A, Gilbert J-A. Overweight and obesity in children and adolescents: results from the 2009 to 2011 Canadian Health Measures Survey. *Health Rep.* 2012; 23(3):37–41. PubMed

104. Robinson S. Victimization of obese adolescents. *J Sch Nurs.* 2006; 22(4):201–206. PubMed doi:10.1177/10598405050220040301

105. Robinson TN, Matheson D, Desai M, et al. Family, community and clinic collaboration to treat overweight and obese children: Stanford GOALS—A randomized controlled trial of a three-year, multi-component, multi-level, multi-setting intervention. *Contemp Clin Trials.* 2013; 36(2):421–435. PubMed doi:10.1016/j.cct.2013.09.001

106. Rodenberg RE, Gustafson S. Iron as an ergogenic aid: iron-clad evidence? *Curr Sports Med Rep.* 2007; 6(4):258–264. PubMed

107. Rodriguez NR, DiMarco NM, Langley S. American Dietetic Association, Dietitians of Canada, American College of Sports Medicine: Nutrition and Athletic Performance. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc.* 2009; 109(3):509–527. PubMed doi:10.1016/j.jada.2009.01.005

108. Romijn JA, Coyle EF, Sidossis LS, Zhang XJ, Wolfe RR. Relationship between fatty acid delivery and fatty acid oxidation during strenuous exercise. *J Appl Physiol.* 1995; 79(6):1939–1945. PubMed

109. Rowland TW. Iron deficiency in the young athlete. *Pediatr Clin North Am.* 1990; 37(5):1153–1163. PubMed

110. Roy BD, Tarnopolsky MA. Influence of differing macronutrient intakes on muscle glycogen resynthesis after resistance exercise. *J Appl Physiol.* 1998; 84(3):890–896. PubMed

111. Schümann K, Ettle T, Szegner B, Elsenhans B, Solomons NW. On risks and benefits of iron supplementation recommendations for iron intake revisited. *J Trace Elem Med Biol.* 2007; 21(3):147–168. PubMed doi:10.1016/j.jtemb.2007.06.002

112. Sehl PL, Leites GT, Martins JB, Meyer F. Responses of obese and non-obese boys cycling in the heat. *Int J Sports Med.* 2012; 33(6):497–501. PubMed doi:10.1055/s-0031-1301314

113. Shields M, Tremblay MS. Canadian childhood obesity estimates based on WHO, IOTF and CDC cut-points. *Int J Pediatr Obes.* 2010; 5(3):265–273. PubMed doi:10.3109/17477160903268282

114. Solomon TPJ, Haus JM, Cook MA, Flask CA, Kirwan JP. A low-glycemic diet lifestyle intervention improves fat utilization during exercise in older obese humans. *Obesity (Silver Spring).* 2013; 21(11):2272–2278. PubMed doi:10.1002/oby.20411

115. Stein TP, Rumpler WV, Leskiw MJ, Schluter MD, Staples R, Bodwell CE. Effect of reduced dietary intake on energy expenditure, protein turnover, and glucose cycling in man. *Metabolism.* 1991; 40(5):478–483. PubMed doi:10.1016/0026-0495(91)90228-O

116. Stephens BR, Cole AS, Mahon AD. The influence of biological maturation on fat and carbohydrate metabolism

during exercise in males. *Int J Sport Nutr Exerc Metab.* 2006; 16(2):166–179. PubMed

117. Strauss RS, Pollack HA. Social marginalization of overweight children. *Arch Pediatr Adolesc Med.* 2003; 157(8):746–752. PubMed doi:10.1001/archpedi.157.8.746

118. Tarnopolsky LJ, MacDougall JD, Atkinson SA, Tarnopolsky MA, Sutton JR. Gender differences in substrate for endurance exercise. *J Appl Physiol.* 1990; 68(1):302–308. PubMed

119. Taylor ED, Theim KR, Mirch MC, et al. Orthopedic complications of overweight in children and adolescents. *Pediatrics.* 2006; 117(6):2167–2174. PubMed doi:10.1542/peds.2005-1832

120. Thackray AE, Barrett LA, Tolfrey K. Acute high-intensity interval running reduces postprandial lipemia in boys. *Med Sci Sports Exerc.* 2013; 45(7):1277–1284. PubMed doi:10.1249/MSS.0b013e31828452c1

121. Tiggemann M. Body dissatisfaction and adolescent self-esteem: prospective findings. *Body Image.* 2005; 2(2):129–135. PubMed doi:10.1016/j.bodyim.2005.03.006

122. Timmons BW, Bar-Or O, Riddell MC. Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men. *J Appl Physiol.* 2003; 94(1):278–284. PubMed doi:10.1152/japplphysiol.00140.2002

123. Tolfrey K, Thackray AE, Barrett LA. Acute exercise and postprandial lipemia in young people. *Pediatr Exerc Sci.* 2014; 26(2):127–137. PubMed doi:10.1123/pes.2013-0126

124. Tsalis G, Nikolaidis MG, Mougios V. Effects of iron intake through food or supplement on iron status and performance of healthy adolescent swimmers during a training season. *Int J Sports Med.* 2004; 25(4):306–313. PubMed doi:10.1055/s-2003-45250

125. Volterman KA, Obeid J, Wilk B, Timmons BW. Effects of postexercise milk consumption on whole body protein balance in youth. *J Appl Physiol.* 2014; 117(10):1165–1169. PubMed doi:10.1152/japplphysiol.01227.2013

126. Walsh M, Cartwright L, Corish C, Sugrue S, Wood-Martin R. The body composition, nutritional knowledge, attitudes, behaviors, and future education needs of senior schoolboy rugby players in Ireland. *Int J Sport Nutr Exerc Metab.* 2011; 21(5):365–376. PubMed

127. Weintraub DL, Tirumalai EC, Haydel K, Fujimoto M, Fulton JE, Robinson TN. Team sports for overweight children: The stanford sports to prevent obesity randomized trial (sport). *Arch Pediatr Adolesc Med.* 2008; 162(3):232–237. PubMed doi:10.1001/archpediatrics.2007.43

128. WHO Multicentre Growth Reference Study Group. *WHO child growth standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for- age: Methods and development.* Geneva: World Health Organization; 2006.

129. Wilk B, Kriemler S, Keller H, Bar-Or O. Consistency in preventing voluntary dehydration in boys who drink a flavored carbohydrate-NaCl beverage during exercise in the heat. *Int J Sport Nutr.* 1998; 8(1):1–9. PubMed

130. Wycherley TP, Noakes M, Clifton PM, Cleanthous X, Keogh JB, Brinkworth GD. A High-Protein Diet With Resistance Exercise Training Improves Weight Loss and Body Composition in Overweight and Obese Patients With Type 2 Diabetes. *Diabetes Care.* 2010; 33(5):969–976. PubMed doi:10.2337/dc09-1974

131. Zunquin G, Theunynck D, Sesboüé B, Arhan P, Bouglé D. Comparison of fat oxidation during exercise in lean and obese pubertal boys: clinical implications. *Br J Sports Med.* 2009; 43(11):869–870. PubMed doi:10.1136/bjsm.2007.044529

132. Zunquin G, Theunynck D, Sesboue B, Arhan P, Bougle D. Evolution of fat oxidation during exercise in obese pubertal boys: clinical implications. *J Sports Sci.* 2009; 27(4):315–318. PubMed doi:10.1080/02640410802578172