Childhood obesity: global trends, health complications, and prevention needs

Angelo Pietrobelli, Julia Kerns and Myles S. Faith

Verona, Italy and Philadelphia, USA

***Background*: Childhood obesity, a disorder that is increasing in prevalence globally, is associated with medical complications that were primarily seen in adults, and is challenging to manage clinically. The challenges of childhood obesity are not limited to one country, but confront most nations around the world. This review article addresses the following issues concerning pediatric overweight and obesity: global prevalence trends, assessment of fat mass in growing children, medical comorbidities and Type 2 diabetes, and the efficacy of obesity treatment.**

***Data sources and study selection*: We analyze trends and prevalence around the world and present research and clinical setting measures of body composition. Comorbidities and Type 2 diabetes are discussed in light of increasing prevalence globally. Intervention as well as prevention data are summarized in order to offer a complete view of the possibilities available for daily clinical practice. We outline directions for prevention research, one of the most pressing needs in biomedical research.**

***Conclusions*: We conclude by outlining efforts to manage and prevent childhood obesity that involves education, research and intervention. Education and research can inform prevention efforts and assist with the development of public policy to manage the problem. Further research exploring the health risks associated with childhood obesity is needed to guide treatment efforts.**

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Author Affiliations: Pediatric Unit, Verona University Medical School, Verona, Italy (Pietrobelli A); University of Pennsylvania School of Medicine (Kerns J and Faith MS)

Corresponding Author: Myles S. Faith, PhD, Weight and Eating Disorders Program, 3535 Market Street-3rd Floor, Philadelphia, PA 19104, USA (Tel: 1-215-8987314; Fax: 1-215-8982878; Email: mfaith@mail.med.upenn.edu)

Global trends and prevalence

The International Obesity Task Force[1] has estimated that approximately 10% of individuals 5-17 years old were overweight, among which 2%-3% were obese, in the year 2000. This figure corresponds to 155 million overweight and 30 to 45 million obese children worldwide. Childhood overweight affected approximately 15% of children and adolescents in the United States from 1999 through 2002.[2] Among US children and adolescents aged 6-18 years, the prevalence of overweight increased from 15.4% in 1971-1974 to 25.6% in 1988-1994, and then doubled between 1976-1980 and 1999-2002.[3] The risk of overweight is increased among persons with high birth weight (4000 g or more) and parental obesity.[2] Racial background is also a highly relevant factor, with black and Hispanic children being approximately twice as likely to be obese as white non-Hispanic children.[3,4] The results of several European studies document that childhood obesity has increased steadily over the past three decades with an equal distribution of overweight in European children.[5] The worldwide data on pediatric obesity demonstrate that the increasing prevalence of obesity is an international phenomenon (Table 1).[6-28]

Assessment of body composition methods

The study of childhood obesity requires accurate methods for characterizing growth and nutritional status. This is challenging because the body composition methods used in adults are not directly applicable to pediatric populations. An overview of whole-body and regional measurements methods is provided in the following section. We have reviewed the methods that are considered appropriate for research and clinical settings.

Research setting methods

Hydrodensitometry

The hydrodensitometry system consists of a large tank of water and a scale. The subject exhales maximally, submerges, and body weight is recorded. This is an estimate of underwater weight; the subject's body weight is then measured outside the tank. The results are used to calculate body volume and body density. The body density is then used to calculate the proportion of body weight as fat mass (FM) and fat free mass (FFM).[29] Recent developments of this method use air rather than water displacement, in a device called a BOD-POD. An exciting development in the application of air-displacement plethysmography in the testing of infants (< 1 year old) has recently emerged. Life Measurement Incorporated has developed an air-displacement plethysmograph specifically for infants between birth and 6 months of age with body masses of 2.7-7.4 kg.[30]

Table 1. Prevalence of pediatric obesity worldwide

Country	Date of survey	Age (years)	Prevalence (%)	References
South America				
Argentina	2000	2-5	7.2	de Onis & Blossner, 2000[8]
Bolivia	1998	2-5	6.5	de Onis & Blossner, 2000[8]
Brazil	1996	2-5	8	de Onis & Blossner, 2000[8]
	1997	6-18	14 (overweight + obesity)	Wang et al, 2002[6]
Chile	1996	0-5	7	de Onis & Blossner, 2000[8]
	2000	6-19	7 (m), 8 (f)	Kain et al, 2002[7]
Columbia	1995	2-5	2.5	de Onis & Blossner, 2000[8]
Mexico	2000	0-5	4.9	Gonzales et al, 2004[9]
	2003	<5	5.5	Avila et al, 2003[10]
Peru	1996	2-5	6	de Onis & Blossner, 2000[8]
Uruguay	2000	2-5	6.1	de Onis & Blossner, 2000[8]
Venezuela	1997	2-5	3	de Onis & Blossner, 2000[8]
North America				
Canada	1996	7-13	10 (m), 9 (f)	Tremblay et al, 2002[11]
USA	1988-1994	6-11	11	Troiano et al, 1995[12]
		12-17	13 (m), 9 (f)	
	1988-1994	6-11	8 (m), 7 (f)	Flegal et al, 2001[13]
		12-17	8	
Europe				
Austria	2002-2003	10-15	9 (m), 5 (f)	Widhalm and Dietrich (personal communication, 2003)
France	1990	4-17	3	Rolland-Cachera et al, 2002[14]
Germany	1995	7-14	8 (m), 10 (f)	Kromeyer-Hauschild et al, 1999[15]
Greece	1998	12	18 (m), 5 (f)	Mamalakis et al, 2000[16]
	2000	6-17	4	Krassas et al, 2001[17]
Italy	1994-2000	6-20	4	Cacciari et al, 2002[18]
Portugal	2003	7-10	9 (m), 12 (f)	Padez et al, 2003[19]
Russia	1998	6-18	9	Wang et al, 2002[6]
Spain	1995	6-15	6 (m), 2 (f)	Moreno et al, 2000[20]
	1995	6-15	7	Rios et al, 1999[21]
Sweden	1997	12-18	8 (m), 4 (f)	Berg et al, 2001[22]
Switzerland	1999	6-12	10	Zimmermann et al, 2000[23]
UK	1998	7-11	5 (m), 4 (f)	Lobstein et al, 2003[24]
Africa				
Algeria	1996	2-5	9	de Onis & Blossner, 2000[8]
Egypt	1996	2-5	8.5	de Onis & Blossner, 2000[8]
	1997	10-19	4	Ibrahim et al, 2002[25]
Iran	1995	2-11	3	de Onis & Blossner, 2000[8]
Marocco	1992	2-5	6.5	de Onis & Blossner, 2000[8]
S. Africa	1996	2-5	6.5	de Onis & Blossner, 2000[8]
Tunisia	1988	2-5	4	de Onis & Blossner, 2000[8]
Asia-Pacific region				
Australia	1995	2-18	5	Magarey et al, 2001[26]
China	1995	6-18	8 (m), 7 (f)	Ke-You & Da-Wei, 2001[27]
India	2002	13-18	4 (m), 3 (f)	Ramachandran et al, 2002[28]

Countries selected with all information available.

Bioimpedance analysis
Bioimpedance analysis (BIA) is based on measurement of electrical resistance in the body to a tiny imperceptible current. This approach provides an estimate of total body water, which can be transformed into fat free mass. The main concept of BIA is that tissues rich in water and electrolytes are less resistant to the passage of an electrical current than lipid-rich adipose tissue. BIA methods require use of appropriate equations (age and population specific), standard measurement conditions, and several other factors (body position, time of the day, and room temperature).[27,31] Prediction equations should only be applied to the population for whom the regression equation has been developed.

Dual energy X-ray absorptiometry
Dual energy X-ray absorptiometry (DXA) quantifies the relative attenuation of two main photon peaks as they pass through tissue. The relative attenuation of the two photon streams is a function of tissue elemental composition. This technique is more feasible with children for whom other laboratory techniques may be impractical (underwater weighing). The greatest advantage of DXA may be the ability to assess regional body composition (trunk, arms and legs). An example of a research use of DXA that may lead to clinical application is the prediction of co-morbidity risk in obese children and adolescents.[32]

Imaging
Computerized axial tomography (CT) and magnetic resonance imaging (MRI) provide investigators with the opportunity to evaluate tissue-system level components *in vivo*.[33] In particular, the effect of fat distribution on disease risk is a subject of great interest. In children and adolescents, recent studies have related central fat to Type 2 diabetes mellitus and cardiovascular disease.[34] Imaging can inform the origins of the relationships between visceral adipose tissue and adverse health and also explain the influence of ethnic and gender differences in adipose tissue distribution.[35]

Clinical setting methods
Anthropometry is the least expensive and most widely used method for assessing pediatric body composition, and is especially informative for epidemiological studies.

Body mass index
Body mass index (BMI) is defined as weight (kg)/height squared (m^2) and is widely used as an index of relative adiposity. For children, various cut-off criteria have been proposed based on reference populations and statistical approaches. BMI varies with age and gender. It typically rises during the first month after birth, falls after the first year and rises again around the six years of life (adiposity rebound). A given value of BMI therefore needs to be evaluated against age- and gender-specific reference values. Children with a BMI greater or equal to the 95th percentile for age and gender are generally classified as "overweight" and children with a BMI between the 85th and 95th percentile as "at risk of overweight".[36] Using data from different nations, Cole et al [37] derived curves that passed through the points of 25 and 30 BMI at age 18 years. These were used to provide age and gender specific BMI cut offs to define childhood overweight and obesity.

Skinfolds
Skinfold thickness measurements are widely applied in pediatric subjects, using special calipers to grasp a skinfold at different sites of the body (triceps, subscapular). Prediction equations can be used to estimate fat mass and fat percentage from the skinfold measurements.[35]

Waist circumference
Waist circumference is an indirect measure of central adiposity, which itself is correlated with risk of cardiac disease and adverse lipid profile.[38] Waist circumference is measured at the minimum circumference between the iliac crest and the rib cage using an anthropometric tape.[39] Recently, normative percentiles have been published in the United States for waist circumference measures for children age 2 to 18 years in three major ethnic groups (African-American, European American, Mexican-American), using data from the Third National Health and Nutrition Examination Survey (NHANES III) (Table 2). These can be used to assess trends, compare individual children to population norms, and to compare populations to public health recommendations.[40]

Comorbidities of childhood obesity
Childhood obesity is linked to multiple health risks including elevated blood pressure, respiratory abnormalities, dyslipidemia, hyperinsulinemia and health complications that are precursors to Type 2 diabetes.[41]

Blood pressure
There is an association between adiposity and elevated blood pressure in children and adolescents.[42-45] Elevated blood pressure occurs approximately nine times more frequently among obese than nonobese children.[44] One

Table 2. Waist circumference according to sex for African-American, European-American and Mexican-American children[40]

Age	European Americans				African Americans				Mexican Americans			
	Boys		Girls		Boys		Girls		Boys		Girls	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
2	47.973	0.246	48.084	0.274	47.191	0.228	46.514	0.301	48.051	0.233	48.353	0.288
3	49.565	0.268	49.634	0.343	49.296	0.273	48.975	0.306	51.118	0.344	51.167	0.416
4	51.462	0.280	51.957	0.403	50.847	0.301	50.817	0.388	53.576	0.451	52.836	0.479
5	52.989	0.378	53.592	0.476	52.869	0.408	52.510	0.342	54.024	0.422	54.653	0.542
6	57.246	1.018	54.055	0.941	53.383	0.595	55.845	0.951	56.354	0.749	56.293	1.052
7	58.605	1.112	57.875	1.322	56.311	0.726	59.113	1.194	60.901	1.623	57.769	0.782
8	58.815	0.838	58.437	0.878	58.359	0.862	61.174	1.146	62.917	1.068	62.664	1.109
9	63.980	1.329	63.571	1.672	60.930	0.929	62.423	1.088	64.633	1.256	64.719	1.618
10	66.343	1.377	64.929	1.798	63.740	1.047	65.814	1.314	67.480	1.219	64.370	0.886
11	67.359	1.411	67.945	1.189	68.594	1.440	68.628	1.241	74.093	1.785	73.412	2.182
12	72.410	1.333	68.822	1.662	71.300	1.952	70.606	1.234	73.214	1.641	73.538	1.339
13	73.223	1.659	74.348	1.696	71.400	2.111	74.819	1.422	77.332	1.595	73.700	1.484
14	80.041	3.631	74.591	1.377	73.823	1.730	77.328	2.145	74.940	1.574	75.203	1.148
15	81.187	2.443	74.067	1.318	74.947	1.221	79.535	3.366	79.584	2.056	76.861	1.439
16	78.990	1.529	76.652	1.909	74.894	1.157	78.052	1.457	80.686	1.219	76.043	1.408
17	81.867	1.620	77.300	1.385	76.126	1.327	79.357	1.720	81.903	1.532	82.342	1.877
18	81.066	1.824	76.757	1.459	79.267	1.625	83.071	2.425	84.447	1.664	81.266	1.921

study examined data from over 3000 5 to 18 year old males and females[45] and found that fatness in excess of 25% in males and 30% in females was associated with increased risk for hypertension. Similar findings have also been noted among 5- and 6-year-old Hispanic children.[46] Daniels et al[47] examined the predictors of left atrial enlargement in children and adolescents with essential hypertension, and found that BMI was significantly elevated among participants with vs without left atrial enlargement.

Respiratory abnormalities

In nonobese individuals, there is usually little fat deposition in the neck and in the peripharynx regions. Increased neck adiposity is associated with respiratory abnormalities during sleep among pediatric individuals. Respiratory complications associated with childhood obesity include asthma, obstructive sleep apnea, and pickwickian syndrome.[48-49] Sleep apnea is especially common in childhood obesity.

Lipids and lipoproteins

Pediatric obesity is associated with elevated levels of total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides, and decreased levels of high-density lipoprotein (HDL) cholesterol.[50-53] Freedman et al[54] studied 10 to 17-year-old children from the Bogalusa Heart Study and found that children who were at risk for overweight or who were overweight were 2.4 times as likely as normal weight children to have elevated total cholesterol, diastolic blood pressure, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, systolic blood pressure, triglycerides, and fasting insulin. Several of these associations differed between whites and blacks, and by age.

Glucose intolerance, insulin resistance, hyperinsulinemia, and Type 2 diabetes

Body fatness is a reliable correlate of hyperinsulinemia and glucose intolerance among adolescent males and females.[55-59] It has been proposed that hyperinsulinemia may underlie the associations among obesity, hypertension, and glucose intolerance.[60] These associations have been documented in pediatric samples.[58,61] Impaired glucose tolerance is a condition indicated by elevated blood sugar levels, but not the levels high enough for a diagnosis of Type 2 diabetes. A clinic-based study found that 25% of obese children 4 to 11 years old, and 21% of obese children 11 to 18 years old, had impaired glucose tolerance.[62]

Insulin resistance, another precursor to Type 2 diabetes, is also related to childhood obesity.[63] In a school-based study of over 12 000 5th to 8th grade boys and girls, Sinaiko et al[64] found significant associations between insulin resistance and body fat. The greatest insulin resistance was also associated with elevated triglycerides and LDL cholesterol, reduced HDL cholesterol, and elevated blood pressure.

The prevalence of Type 2 diabetes in children appears to be increasing. In an analysis of 1027 children and adolescents attending a Cincinatti clinic, only 4% were diagnosed with Type 2 diabetes mellitus before

1992.[65] By 1994, 16% of new cases of Type 2 diabetes were diagnosed in that age group, with 10 to 19 years old representing 33% of all those cases. This translated into a 10-fold increase in the incidence of diabetes within the 10 to 19-year-old age group.

Treatment of child obesity

Family-based behavioral treatment programs have been the most extensively studied interventions to date and generally achieve the best short- and long-term results. Treatment strives to teach the family members the behavioral skills necessary to establish and sustain healthier eating and physical activity patterns. Behavior modification strategies such as behavioral contracting, stimulus control, and positive reinforcement therefore set the foundation to help children lose weight.[66-68] Behavioral contracting refers to an explicit "contract" among family members that stipulates the behavioral goals that family members will attempt to reach and the reinforcements they will receive for attaining such goals. Rewards other than food and money are utilized. Family-based and interpersonal rewards are used instead (praise, family trips, sports equipment). Stimulus control refers to practical restructuring of the physical home environment such that healthier foods become more readily accessible whereas high-fat, high-sugar foods are less accessible. Positive reinforcement strategies for families form the foundation for treatment, as parents are trained to move away from punitive parenting strategies to more positive parenting strategies.

Research suggests that dietary modification is a powerful and necessary component for child weight loss. Treatments focusing solely on dietary modification have achieved short-[69-70] and long-term weight losses[71]. Short-term interventions lacking a dietary component achieved mixed results,[72,73] but there is no evidence for long-term efficacy of treatments lacking a dietary component.

Many programs have used Epstein's Traffic Light Diet[74] or a variant for dietary prescriptions. Utilizing the USDA's Food Guide Pyramid as its foundation, children are encouraged to increase intake of low-fat nutrient-rich "Green" foods (fruits and vegetables), to consume moderate-calorie "Yellow" foods in moderation (certain grain foods), and minimize if not eliminate high-fat high-sugar "Red" foods (candies). Detailed lists of food alternatives and their corresponding calories are provided to families, who are encouraged to try new and varied Green and Yellow foods. Most behavioral programs initially strive to reduce children's total daily caloric intake while maintaining adequate nutrition for development and growth. A recommended first step is increasing children's awareness of eating habits through self-monitoring, with parental help. With appropriate reductions of total calories and fat intake, children can meet their nutritional needs through increasing the nutrient density of foods eaten, shift toward negative energy balance, and gradually substitute for unhealthy food choices.

The most successful pediatric obesity programs have typically (but not always) included a physical activity component.[75] There appear to be consistent short-term effects of physical activity interventions on both children's weight status and cardiorespiratory fitness.[76] Planned aerobic sessions seem to be more beneficial for children's weight loss than lower energy expenditure calisthenics programs;[75] however, for long-term weight maintenance, data suggest that the best results are achieved through lifestyle approaches that attempt to weave physical activity into every day living (climbing stairs instead of taking the elevator, parking one's car at a distance from a supermarket, walking to the grocery store).[73,75]

Weight loss can also be achieved by targeting reductions in sedentary activities (TV viewing) rather than targeting increased physical activity per se.[76-77] These studies show that children who discontinue sedentary activities will naturally redistribute some (although not all) of their time to physical activity which facilitates weight loss. Hence, targeting reduced sedentary activity (TV viewing, video games, computers) has become a vital treatment strategy.

Prevention

The prevention of childhood obesity is one of the most pressing needs in the field. There have been virtually no population-based childhood obesity prevention studies, although several notable school prevention studies have yielded encouraging results. Two of the most influential school-based prevention studies in recent years are those by Robinson[78] and Gortmaker et al[79]. Robinson's school-based study compared 192 third- and fourth-grade students (mean age 8.9 years) from two California elementary schools. The intervention consisted of an 18-lesson, 6-month classroom curriculum to reduce television, videotape, and video game use. Compared to the control school, the treatment school demonstrated less of an increase in BMI (intervention vs control changes: 18.38 to 18.67 kg/m^2 vs 18.10 to 18.81 kg/m^2), less of an increase in triceps skin fold measurements (intervention vs control change: 14.55 to 15.47 mm vs 13.97 to 16.46 mm), less of an increase in waist to hip ratio (intervention vs control change: 0.83 to 0.83 vs 0.82 to 0.84), and less of an increase in waist circumference (intervention vs control change: 60.48 to 63.57 cm vs 59.51 to 64.73 cm). The intervention group also demonstrated statistically significant decreases in reported television viewing (intervention vs control change: 15.35 to 8.80 vs 15.36 to 14.46 hours/week). This study provides strong illustration of the potential role of television viewing reduction in obesity prevention.

Gortmaker et al's[79] "Planet Health" obesity prevention program also emphasized reduction of television viewing as a central component in their obesity prevention program. The researchers compared five treatment schools against five control schools in a study that included 1295 ethnically diverse children in grades six and seven in Massachusetts, United States. Over two years, the obesity prevalence among girls in the intervention schools declined from 23.6% to 20.3%, while the prevalence among girls in the control schools increased from 21.5% to 23.7%. Moreover, changes in television viewing practices predicted treatment outcome for girls. Each hour of reduced television watching was independently associated with a 15% reduction in the likelihood of being obese. It should be noted, however, that the control and treatment schools did not differ with respect to obesity incidence (the number of new obesity cases over time).

Recently, James et al[80] conducted a school-based intervention of 7 to 11-year-old designed to reduce consumption of carbonated beverages. The intervention group reduced their intake of carbonated drinks over 3 days. At 1 year, the percentage of overweight and obese children decreased in the intervention group but increased in the control group.

There is a great need for new and innovative studies for research into prevention of childhood obesity. Based on the results of a recent National Institutes of Health conference on this topic, Kumanyika and Obarzanek[81] outlined a list of new avenues for research (Table 3). Perusal of the list reveals the amount of work that remains to be done.

Table 3. Directions for future obesity prevention research[81]

Expand the types of interventions to be tested to prevent obesity and promote weight control and long-term maintenance of weight loss.	• Explore approaches such as participatory action research that encourage community input and have an influence on intervention design and content. • Develop and test interventions that target multiple societal levels, individual-based interventions, and their combination, to determine whether public health and individual approaches are interactive. • Develop and test environmental strategies (in homes, organizations, work sites, neighborhoods), including policy changes. • Develop and test family-based interventions and interventions in the primary health care setting, including physician incentives.
Conduct research to improve efficacy of interventions for obesity prevention and long-term weight control programs.	• Determine optimal intervention duration, frequency, and mode of delivery (group or individual face-to-face contact, telephone, mail, internet). • Use highly controlled study designs to determine optimal physical activity and dietary prescriptions in adults and in children and adolescents. • Determine the optimal use of meal replacements for weight loss and its long-term maintenance. • Test interactive effects of genetic and/or psychosocial predictors of obesity by stratifying study participants on these factors. • Explore and describe approaches to intervention by internet, alone and in combination with other intervention strategies. Gather information on the "dose" of intervention the internet provides and the ability of the internet to enhance motivation and adherence to interventions.
Conduct observational studies to guide interventions for obesity prevention, weight control, and long-term maintenance of weight loss.	• Identify physiological and behavioral characteristics that put individuals at risk for weight gain. • Identify physiological and psychosocial characteristics and other predictors of success in intervention programs. • Identify barriers to enrolling and participating in weight control programs. • Identify approaches and strategies to enhance motivation and adherence to intervention in children and adolescents, women during the prenatal and postpartum period, and other populations.
Use theoretical models to design obesity prevention interventions.	• Incorporate theoretical perspectives from other areas of research in the conceptualization and design of obesity prevention studies; for example, family systems theory, and organizational behavior theory. • Conduct studies in which obesity prevention objectives are integrated with other types of health promotion or behavior change objectives. • Develop more systematic concepts of how interventions can be tailored to specific behaviors, populations, and contexts.
Conduct research to improve measurement methodology for obesity prevention research.	• Develop valid and affordable energy balance measurements suitable for large-scale trials outside of clinical settings. • Identify psychosocial measures most relevant for obesity research and explore whether these psychosocial measures can be standardized and used in weight control trials. • Determine a health-related and functional definition obesity in children.

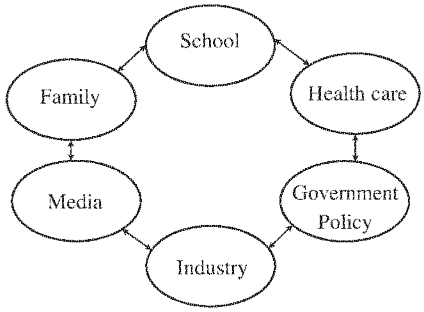

Fig. Potential levels for childhood obesity prevention.

Conclusion

A major concern related to childhood obesity is that obese children tend to become obese adults, with all the risks/comorbidities associated (diabetes, cardiovascular diseases, among many others). Efforts to manage and prevent childhood obesity involve education, research and intervention. Research could drive new directions in prevention and develop public policy that might help manage the problem. Additionally, research is needed to test these issues. In conclusion six relevant levels may be involved in the prevention and treatment of pediatric obesity and each of these needs investigation: family, schools, health care, government, industry and media (Fig.). Together these six levels could promote childhood obesity as a high research priority and put it as the first point in the international public agenda.

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