Natural History of Obesity:  
A Focus on Adolescence

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Adolescence appears to be a high-risk period for the development of obesity, particularly in girls (1). Adolescent obesity is associated with increased morbidity (2) and is more likely to track into adulthood (1). Additionally, adolescent obesity is often associated with adverse psychosocial well-being (2). Therefore the identification of factors that increase susceptibility to obesity during adolescence is essential in the prevention and treatment of adolescent obesity. This chapter will discuss the normal changes in fatness and body fat distribution that occur throughout the adolescent period, and consider factors that may influence these changes.

MEASUREMENT OF BODY FATNESS

Laboratory Methods

Body fatness can be measured directly by laboratory techniques. These include measures of total body water by isotopic dilution, body density by underwater weighing, potassium content by 40K counting, and fat-free mass by dual-energy x-ray absorptiometry (DEXA). None of these techniques measures body fat directly. All measure fat-free mass based on the assumption that FFM has a constant composition. Once fat-free mass has been estimated, body fat can be calculated by subtracting the fat-free mass from body weight: percentage of body fat = (body weight − fat-free mass)/body weight × 100. Multicompartamental methods to measure different components of body composition will reduce the errors associated with the assumption that FFM has a constant composition, but these methods are limited to research studies. Newer, more sophisticated methods have recently been developed that measure body fat directly. Neutron activation measures total body carbon, which indicates total body fat, but this is a highly specialized method and not available for clinical use.

Bioelectrical impedance (BIA) is not a direct estimate of body composition but provides an estimate of body water. Body fat is then calculated from the difference between body weight and fat-free mass, assuming that the latter is 73% water. Measures of body fatness in children and adolescents derived by BIA are
significantly correlated with laboratory measures (3). Measures of change in body
fatness measured by BIA are, however, not well established.

Clinical Methods

Measures of skinfold thickness and body mass index (BMI) have been used to iden-
tify overweight children and adolescents because of the lack of availability of direct
measures of body fatness in a clinical setting. Skinfold thickness provides a measure
of subcutaneous fatness. Two assumptions are inherent in the use of skinfolds to mea-
sure body fatness. The first is that the skinfold site measured is representative of sub-
cutaneous fat. The second is that subcutaneous fat is representative of total body fat.
Because fat distribution changes during childhood and adolescence, the reliance on a
single skinfold measure to assess body fatness may be inaccurate.

Body mass index does not measure fatness but is highly correlated with body fat
measured by laboratory methods. BMI changes with growth and development in chil-
dren. Therefore, criteria for identifying overweight will depend on age and sex.
Furthermore, body composition changes with growth and development. As discussed
by Troiano et al. (4), BMI to identify overweight in children should be used cau-
tiously because body composition (e.g., bone mass and the proportion of lean and fat
tissues) changes at different times and rates during growth and development.

Many of the reported studies on serial changes of body fatness in children and ado-
lescents are based on measures of skinfold thickness, BMI, and BIA. It is therefore
important to keep in mind the limitations of these measurements when interpreting
studies. All represent indirect measures of body fatness and it is unclear how well
they assess change.

MEASURES OF BODY FAT DISTRIBUTION

Because fat distribution is an independent risk factor associated with the adverse ef-
effects of obesity, it is now the subject of many investigations. Increased abdominal fat
is often characterized as upper body fatness, increased truncal fatness, or a central
body fat distribution. Generally, a central or truncal body fat distribution refers to ex-
cess fat in the trunk rather than peripherally—that is, in the arms and legs. Upper
body fat distribution is essentially the same as central or truncal body fat, but refers
more specifically to an excess of body fat in the upper body.

Many investigators use body circumferences, such as the waist-to-hip ratio or
waist circumference, to identify upper-body fat distribution or a central or truncal
pattern of distribution. Others use skinfold thickness. Biceps and triceps skinfolds
represent peripheral fat stores, whereas abdominal or subscapular skinfold thickness
represents truncal fat stores. However, skinfold thickness measures only subcuta-
neous fat, not intraabdominal adipose tissue.

Intraabdominal adipose tissue appears to be associated with the adverse effects of
an upper-body fat distribution (5,6). To differentiate subcutaneous abdominal fat and
intraabdominal adipose tissue, magnetic resonance imaging (MRI) or computed to-
mography (CT) scans are necessary.
Many investigators have studied the relation between anthropometric measurements—such as skinfold thickness and body circumferences—and intraabdominal adipose tissue in children and adolescents. De Ridder et al. (7) reported a significant relation between waist circumference and intraabdominal fat in a small sample of girls but no correlation between waist-to-hip ratio and intraabdominal fat. Brambilla et al. (8) also did not find a significant relation between waist-to-hip ratio and intraabdominal fat. Goran et al. (9) and Fox et al. (10) report a stronger relation of trunk skinfold measures than waist-to-hip ratio with intraabdominal adipose tissue. Waist circumference was significantly correlated with intraabdominal adipose tissue in both girls and boys in Fox’s initial study (10). However, in their follow-up study (11), waist circumference was not correlated with intraabdominal adipose tissue.

Although it appears that the waist-to-hip ratio may be of value in determining the upper- or lower-body fat distribution of subcutaneous tissues, it is not a useful index of intraabdominal adipose tissue. Trunk skinfold thickness and waist circumference do not give a reliable measure of intraabdominal adipose tissue either, but overall show a better correlation than the waist-to-hip ratio. It also appears that the value of an anthropometric measurement may differ with the stage of sexual maturation.

MEASURES OF MATURATION

Stages of puberty are based on Tanner staging of sexual development (12) and peak height velocity. Tanner staging is somewhat subjective, and the measure of peak height velocity requires serial measurements. Menarche is the only defined time point. Sex hormones may provide direct measures of pubertal status but are often lacking from most studies. Thus studies of the effect of puberty and pubertal stage on obesity may be limited by the measures available to identify periods of maturation.

BODY COMPOSITION THROUGH CHILDHOOD AND ADOLESCENCE

Body fatness changes throughout the period of childhood and adolescence. Twenty-five years ago, Dugdale and Payne (13), using published data on body weight and body composition at various ages, calculated the changes in lean and fat tissue from birth to 17 years of age. They identified periods of lean and fat deposition during childhood and adolescence. Fat deposition predominates in the first year of life, but from then to age 4 years lean tissue deposition predominates. Between 6 and 10 years of age fat deposition increases again. Lean mass deposition increases during adolescence, but by age 17, fat deposition once more predominates. Recent body composition studies have confirmed these cycles of fat deposition and will be reviewed later. I will discuss the period of infancy and prepuberty only briefly and concentrate on the changes during adolescence.

Infancy and Childhood

Recently, body composition in infants through 2 years of age has been studied using a multicomponent model (14). Fat mass as a percentage of body weight increased
during the first 6 months and then declined. At 6 and 9 months of age, percentage of body fat was higher in girls than boys.

Differences in body composition in prepubertal boys and girls are small (15). Recently, Taylor et al. (16) measured body composition in 3- to 8-year-old children using DEXA. They observed a significantly higher percentage of body fat and smaller amounts of lean tissue in girls in comparison to boys matched for age, height, weight, and BMI. Their data suggest that sexual dimorphism observed in adolescents may begin before puberty. However, only 20 pairs of boys and girls were measured. Further studies on larger numbers of children are needed to verify these findings.

Increases in body fat in both boys and girls begin after 4 to 5 years of age, a period labeled the “adiposity rebound” (17). It has been suggested that an earlier increase in adiposity rebound may be a risk period for the development of obesity (18).

**Pubertal Period**

During the pubertal period, significant changes in linear growth and body composition occur. These changes differ considerably among boys and girls. While both boys and girls gain lean body mass, boys gain significantly more than girls. Cheek measured total body water in a large cohort of boy and girls of various ages (15). In boys, lean body mass almost doubled from the age of 10 to 15, although there was little change in fat mass. Girls also show large increases in fat-free mass during puberty, although not to the same extent as boys. Girls, however, also gained significant amounts of body fat. This chapter will focus on these changes in body fatness and fat distribution that occur during the adolescent period and the factors that contribute to these changes.

Studies that have examined the change in body composition in girls and boys during puberty have found differences not only in the amount of fat-free mass accretion but also in the rate of accretion. In the Fels longitudinal study (19), girls showed an increase in fat-free mass that slowed over the teenage years, whereas boys showed a continual increase until they reached young adulthood.

**Energy Cost of Growth in Adolescence**

Many people believe that rapid growth during adolescence increases the energy requirements significantly. However, the extra energy needed to support growth during the adolescent period is relatively small. Approximately 1% to 3% of daily energy expenditure during this period can be attributed to the energy cost of growth.

The cost of excess weight gain is also small. A girl who is at the 50th centile for weight at 9 years of age will be close to the 95th centile of weight for age at 13 if she gains an excess of 4 kg a year. Assuming that this adipose tissue has an energy cost of 7,200 kcal, this would translate to an excess of 80 kcal. Thus growth and excess weight gain do not require large amounts of energy, and the common notion that adolescents need lots of extra energy to support growth is unfounded.
Ethnic Differences in Body Composition

Studies have shown that girls who mature earlier are heavier and fatter than girls who mature later and that early maturation is associated with increased risk of subsequent obesity (20). Morrison et al. (21) observed racial differences in sexual maturity and body composition among black and white 9- and 10-year-old girls. They found more black than white girls were pubertal at age 9 and 10, and observed racial differences in body composition among 9- and 10-year-old girls at Tanner stage 2. Thus black girls at this stage had greater weight, height, BMI, and skinfold thickness than white girls. In Morrison’s study (21), differences in fatness among black and white girls were observed during puberty but not before puberty, suggesting that puberty is associated with the increase in fatness in black girls. However, in the NHANES III study conducted in the United States between 1988 and 1991, non-Hispanic black girls had a higher prevalence of overweight than white girls during both childhood (6 to 11 years) and adolescence (12 to 17 years) (4).

Longitudinal studies comparing weight changes and body fatness among black and white girls are needed to support the suggestion that during puberty ethnic differences are associated with an increased incidence of obesity in black girls. Data on body fatness among other ethnic groups are limited.

Persistence into Adult Life

It has been proposed that adolescence is a period of increased risk for obesity in girls (1). Among the most concerning consequences of childhood and adolescent obesity is its persistence into adulthood, where it is associated with the morbidity and premature mortality characteristic of adult obesity (2). Furthermore, Must et al. (22) have shown that men who were obese as adolescents had an increased risk of all-cause mortality and an increased risk of cardiovascular disease independent of whether they were obese as adults.

In a retrospective longitudinal study, Whitaker et al. (23) have shown that the persistence of childhood obesity into adulthood increases with age. An obese adolescent will be more likely to become an obese adult than an obese toddler. Studies that have examined whether persistence is related to gender have produced inconsistent findings. Must and Strauss (2) have reviewed the literature and report that some but not all of the studies show greater persistence in obese adolescent females than in obese adolescent males. Parental obesity and severity of obesity also increase the risk that an obese child will become an obese adult (2,23).

Data are needed to determine whether pubertal changes occurring during adolescence in girls may be related to the increased risk of obesity.

Changes in Fat Distribution During Adolescence

Cross-sectional studies have been conducted to examine the change in fat distribution in childhood and adolescence, but few longitudinal data are available.
Changes in the distribution of body fat during puberty from peripheral to central sites are much more pronounced in boys than in girls (24). Obesity in both male and female adolescents has been associated with an increase in truncal fat (25). In a study of obese and nonobese female and male adolescents, using densitometry to measure body fat and skinfold thickness to examine body fat distribution, Hattori et al. found that obese adolescents had more truncal fat than nonobese adolescents (25). Obese girls tended to have more truncal fat at the subscapular site, while obese boys had more in the abdominal area. Cowell et al. conducted a cross-sectional study of body fatness in individuals from 4 to 35 years of age using DEXA (26). They found that in female subjects there was a tendency for a more central distribution of body fat with increasing adiposity, whereas in male subjects the increase in abdominal fat appeared to be independent of total fat mass.

In the US NHANES I survey, Frisancho and Flegal (27) have shown that early maturation in white children is associated with an increase in body fatness and in the central deposition of body fat. Deutsch and Mueller, however, found that early maturation in boys had an effect on fat distribution but not on fatness, whereas in girls early maturation was associated with fatness but not with fat distribution (28).

Van Lenthe et al. (29) conducted a longitudinal study on the changes in skinfold thickness between the ages of 13 and 27 years in males and females as part of the Amsterdam Growth and Health Study (AGHS). They measured four skinfolds and constructed ratios to represent a truncal pattern of fat distribution. Skinfold ratios of girls with early and late menarche differed as follows: Girls with early menarche had significantly higher skinfold ratios than girls with late menarche, suggesting that early maturation is associated with an increase in truncal fat distribution. They did not find an analogous difference in skinfold ratio in relation to maturation in boys as reflected by skeletal age. Given the association of a central fat distribution to increased risk of cardiovascular disease and diabetes, as well as the psychologic impact of early menarche on young girls, it is critical to better understand the interrelationships among these variables.

Factors Associated with a Central Distribution of Body Fat

In girls during early puberty, de Ridder et al. have shown that fat distribution is associated with estradiol and testosterone levels (30). Several studies suggest that the endocrine effects on fat distribution may be modified by behavioral factors. Smoking (31), alcohol use (32), and decreased physical activity (32) appear to be associated with a centralized fat distribution in adults, at least in cross-sectional studies. As discussed earlier, Van Lenthe reported an association between early menarche and fat distribution in the AGHS study (29). In another aspect of the AGHS study, Post and Kemper report that early-maturing adolescents were less physically active than slower-maturing adolescents (33). Whether physical activity patterns will alter fat distribution during adolescence needs more study.

There are limited data on the association of diet and changes in body fatness. Findings by Berky et al. from a historical cohort of girls suggest that diet and body
size are associated with age at peak height velocity and peak growth velocity (34). The age at which girls reached peak growth velocity was younger for girls who were taller before 6 years of age and for those who consumed more animal fat between the ages of 6 and 8. They also suggest that diets higher in protein are associated with earlier menarche. This observation has not been reported elsewhere. Whether macronutrient composition of the diet has an effect on growth and development or fat distribution is unknown.

**Intraabdominal Adipose Tissue**

Upper-body fatness in adults has been associated with increased risk of cardiovascular disease independent of total body fatness. Using DEXA to estimate regional body fatness, Daniels et al. showed that truncal fat distribution in children and adolescents was positively correlated with triglyceride levels, systolic blood pressure, and left ventricular mass, and inversely correlated with high-density lipoprotein (HDL) levels (35). Furthermore, they found that fat distribution was more highly correlated with cardiovascular risk factors than was the percentage of total body fat.

In adults, increases in intraabdominal fat have been associated with increased risk of morbidity and mortality. Caprio et al. observed a relation between increased visceral fat and glucose metabolism in obese adolescent girls (5). When they compared girls with similar degrees of obesity but differing amounts of visceral adipose tissue, they found that the group with greater visceral fat deposition had higher insulin levels, both when fasting and in response to glucose stimulation. They also reported that obese adolescent girls with higher levels of visceral adipose tissue had lower HDL cholesterol and higher triacylglycerol levels, both of which are risk factors for cardiovascular disease (6). However, Brambilla et al. suggest that the effect of intraabdominal adipose tissue on metabolic risk factors may differ during and after the pubertal period (36). Although the amount of intraabdominal fat did not change over the pubertal period, a significant relation between intraabdominal adipose tissue and glucose metabolism was observed only after puberty (36). Furthermore, intraabdominal adipose tissue was significantly related only to low-density lipoprotein cholesterol before puberty and in the early stages of pubertal development. Four years later the only significant relation among lipoproteins and intraabdominal adipose tissue was a negative one with HDL.

Recently, several studies have measured visceral adipose tissue stores in children and adolescents using MRI scans (8,10,11,38,39). These data provide information on the intraabdominal adipose tissue depots in children and adolescents at various ages. Table 1 summarizes the results of published studies on intraabdominal fat in children and adolescents. Most of the available data are for the early adolescent period. Because many of the studies did not publish the values for intraabdominal subcutaneous fat or the ratio of intraabdominal adipose tissue to total body fat, this information is not provided in the table.

Fox et al. reported that the excess fat in 11-year-old girls and boys was deposited more frequently as subcutaneous fat than as visceral fat (10). Leung et al. report a
lower ratio of visceral adipose tissue to total abdominal tissue in obese children than in nonobese children (39). This indicates that most of the excess fat in these pubertal children was stored subcutaneously. Brambilla et al. examined longitudinal changes in abdominal fat deposition (36). All the subjects (16 obese boys and girls) had become obese before the age of 8. Subjects were studied three times at approximately 2-year intervals. At the time of the first visit (Table 1) subjects were either prepubertal or in the early stages of puberty. At the last visit, the subjects had completed sexual development. Thus the time period over which the subjects were measured represented the pubertal period. Although the BMI and subcutaneous fat tissue had increased on the third compared with the first visit, intraabdominal fat and relative weight at these two time periods was not significantly different. These findings are consistent with those of Fox et al. (10), suggesting that excess body fatness before puberty is associated with an increase in subcutaneous fat. They are not, however, consistent with those of Goran et al. (9), who presented data only on younger children. Because the increase in the ratio of intraabdominal adipose tissue to total body fat in children from age 4 to 8 years is almost three times that reported in adolescents, Goran et al. suggested that the prepubertal period is an important time for the deposition of intraabdominal fat (9). However, the sample size in Goran’s study was small (N = 16) and the range of intraabdominal adipose tissue large (4 to 21 cm²). Furthermore, there is a large variation in the amount of intraabdominal fat among subjects in all the studies.

Recently, Fox et al. published data on 2-year changes in intraabdominal adipose tissue in the 11-year-old children they previously reported (11). They observed that the increases in abdominal fat for boys during the pubertal period were greater than
those for girls. In boys they observed a much greater increase in intraabdominal fat (69%) than in subcutaneous fat (19.1%). However, in girls there was a 48.4% increase in intraabdominal fat, compared with a 78.1% increase in subcutaneous fat over the 2-year period. Their findings suggest that there is sexual dimorphism in intraabdominal adipose tissue deposition during puberty.

The levels of intraabdominal adipose tissue during early adolescence are considerably lower than those reported for adults (117.9 ± 62.1) (40). Although this suggests that late adolescence may be an important period for the deposition of intraabdominal fat, empirical data are lacking. Longitudinal studies that measure intraabdominal adipose tissue and total body fat from puberty through late adolescence are needed for a better understanding of the timing associated with intraabdominal fat deposition.

Because the pubertal period is associated with a change in the distribution of body fat, it may represent a critical time for fat distribution and intraabdominal fat stores. Few data are available on factors that may increase intraabdominal fat in children. Rommenich et al. reported an inverse correlation between the energy spent on activity and intraabdominal adipose tissue in boys but no significant interrelationship in girls (41). Because of the association between morbidity and fat distribution, it is important to understand both the timing and the factors that may predispose to a central fat distribution.

SUMMARY

It is clear from published reports that there is sexual dimorphism in the changes in body fatness and body fat distribution during adolescence. Body fatness increases in girls and decreases in boys. The change from a peripheral to a more central pattern of deposition of body fat is more pronounced in boys than in girls. Intraabdominal adipose tissue stores in children and adolescents are small compared with those of adults. However, the factors and time periods associated with an increase in intraabdominal fat in children and adolescents remain unknown. Results of ongoing longitudinal studies of growth and development in children and adolescents will help provide answers to these questions.

REFERENCES


NATURAL HISTORY OF OBESITY


DISCUSSION

*Dr. Steinbeck:* Was there any difference in the slopes of the BMI before and after menarche, depending on fatness before menarche? In other words, was the slope higher before menarche in the fatter girls?

*Dr. Bandini:* We did not look at that, mainly because fatness is a continuous variable and separating the subjects in that way would have been very difficult.

*Dr. Bar-Or:* What is your opinion on the relative roles of the environment and predetermined biologic factors in explaining the patterns you showed, especially in the girls? In other words, are we dealing with factors that we can do very little about, or is this a matter of lifestyle or other variables that can be changed in the girls to prevent them from getting fat?

*Dr. Bandini:* There are studies in adults suggesting that changes in intraabdominal fat tissue are related to behavioral factors such as smoking, alcohol use, and physical activity [1,2]. We need to do studies in children and adolescents to determine whether such factors influence fat distribution and intraabdominal tissue in early life, and whether modifying them will change the fat distribution pattern.

*Dr. Rüthishauser:* I was interested to hear that there is an overlap in the amount of intraabdominal adipose tissue between obese and nonobese adolescents. Is it known how much is too much?

*Dr. Bandini:* I don’t think it is known how much is too much in adolescence. I believe that in adults 130 cm² is associated with adverse effects.

*Dr. Dulloo:* In the correlation where you showed that testosterone was the main predictor of variation in intraabdominal fat, there was also an increase in fat-free mass. If you adjust for the increase in fat-free mass, how much of the correlation remains significant?

*Dr. Bandini:* We did not include that in the model, but that is something we could look at.

*Dr. Yanovski:* Would you care to comment on the racial ethnic differences in changes in body adiposity throughout adolescence?

*Dr. Bandini:* In general, the increase in fat deposition seems more marked in blacks than in whites. I cannot comment on other ethnic differences at present.

*Dr. Gortmaker:* Do the differences in body fat distribution by age, sex, and perhaps ethnicity have implications for the kinds of intervention programs we might apply? For example, do you think one might need to do different things for different sexes at different ages?

*Dr. Bandini:* I think diet and physical activity are the two most important factors in maintaining energy balance and avoiding positive energy balance under all circumstances.

*Dr. Gortmaker:* But would you think of emphasizing different things at different ages, because of the differences between the sexes at different ages? Might there be optimal times to prevent obesity from developing?
Dr. Bandini: Behaviors developed before the pubertal period are more likely to persist lifelong, so that's a good time to establish healthy patterns of activity and food intake.

Dr. Freedman: You showed that girls with an early menarche had a more central fat distribution, which continued up to age 27. Is it possible that some of those differences were present even before menarche? For example, could a central fat distribution be a determinant of menarche?

Dr. Bandini: That is possible. There are published data to suggest that may be the case [3].

Dr. Van Dyk: Have you looked at the effect of growth hormone in the differing growth spurts between boys and girls?

Dr. Bandini: No.

Dr. Uassy: In your hormonal profile, did you also include cortisol? I think that cortisol should be explored in these sorts of studies on central obesity.

Dr. Bandini: No, we did not look at cortisol either. We looked at leptin, the sex hormones, and insulin.

REFERENCES