

Visceral Fat in Prepubertal Children: Influence of Obesity, Anthropometry, Ethnicity, Gender, Diet, and Growth

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ABSTRACT Visceral fat, or intra-abdominal adipose tissue (IAAT) lies deep within the abdominal cavity and can only be directly quantified with imaging techniques. IAAT has been detected in children as young as 5 years of age. IAAT generally increases in proportion with general fatness, but the relationship between IAAT and total body fat is complex; in children, a major portion of the variance in IAAT is independent of total body fat. The waist-to-hip ratio and the trunk:extremity skinfold ratio are not good indices of IAAT in children, and central skinfolds and waist circumference alone are highly correlated with IAAT as well as subcutaneous abdominal adipose tissue ($r = 0.85\text{--}0.92$). African-American children have less IAAT than Caucasian children, and gender differences in IAAT become more apparent after adolescence. Preliminary evidence in children suggests that IAAT may have a stronger influence on cardiovascular risk factors than dietary fat intake. Preliminary evidence in children also suggests that acquisition of IAAT during growth is a linear process that occurs in proportion to general increases in body fat. The study of the regulation of IAAT acquisition during childhood development and its relationship with long-term disease risk is in its early infancy and further studies are required. *Am. J. Hum. Biol.* 11:201–207, 1999. © 1999 Wiley-Liss, Inc.

It is hypothesized that the accumulation of visceral fat, or intra-abdominal adipose tissue (IAAT), in children is influenced by “modifiable” factors, such as those associated with diet, body fatness, and physical activity (Gutin and Owens, 1999), as well as “nonmodifiable” factors such as hormone levels (Roemmich and Rogol, 1999), growth and maturation (Malina et al., 1999), gender and genetics (Katzmarzyk et al., 1999). In turn, IAAT is hypothesized to play a central and mediating role relating obesity and lifestyle to increased disease risk in children, including impaired glucose metabolism and cardiovascular risk (Gower, 1999; Caprio, 1999). This article reviews the current literature relating to the influence of obesity, anthropometry, ethnicity, gender, diet, and growth on IAAT in children.

MEASUREMENT OF VISCERAL FAT

Since visceral fat lies within the abdominal cavity it can only be directly quantified with imaging techniques. Both computed to-

mography (CT) and magnetic resonance imaging (MRI) have been used in children and adolescents for this purpose (de Ridder et al., 1992b; Fox et al., 1993; Goran et al., 1995b, 1997). Using these approaches, adipose tissue is measured in cross-sectional area (cm^2), or volume (cm^3). Since these techniques are expensive and involve radiation exposure (for CT), visceral fat is often measured at a single cross-sectional “slice” at an anatomic landmark, usually the level of the umbilicus or the L3–L4 disk space.

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The major advantage of these imaging techniques is the high resolution and ability to identify small deposits of IAAT. In addition, subcutaneous abdominal adipose tissue (SAAT) is also accurately quantified simultaneously. Since MRI does not involve radiation exposure, some investigators have measured adipose tissue in multiple slices of the abdominal area or across the whole body (Chowdhury et al., 1994) to determine adipose tissue volume rather than cross-sectional area at a specific anatomic site. This approach may be an advantage since there is some concern that a single slice of the abdomen may not reflect total visceral fat content as assessed by MRI volume measures (Conway et al., 1995), and further studies in children and adolescents are needed to explore this issue. Despite the radiation exposure associated with CT scanning, the resolution is stronger; for MRI, the subject is required to keep still and any movement can distort the resolution of the image.

Indirect measures of visceral fat include dual energy X-ray absorptiometry (DXA) to measure fat mass in the trunk region and anthropometry (skinfolds and circumferences). The relationships between visceral fat and these indirect measures are discussed later in this review.

INFLUENCE OF BODY FAT ON IAAT

It is currently unclear whether the amount of visceral fat accumulation seen in children is appropriate for the pediatric body size, and whether the observed extremes are related to extremes of general body fatness or to other factors. For example, some studies suggest that IAAT in children increases in proportion to overall fatness (Goran et al., 1995b) as seen in adults (Lemieux et al., 1993), whereas others have shown that obese children tend to accumulate subcutaneous and not visceral fat (Fox et al., 1993).

In healthy young children (6.4 ± 1.2 years; 24.8 ± 5.4 kg), mean IAAT at the level of the umbilicus was 8.3 ± 5.8 cm² and mean SAAT was 65.3 ± 44.8 cm², as measured by CT scanning (Goran et al., 1995b). In 101 African-American and Caucasian obese and non-obese children (7.5 ± 1.7 years; 33.0 ± 12.2 kg body weight; 30 ± 11% body fat), IAAT averaged 30.0 ± 23.0 cm², and varied greatly from 6 cm² to 102 cm² (Goran et al., 1997). SAAT averaged 101 ± 95 cm² and

also varied greatly (range, 8–372 cm²). Using MRI in healthy 11- and 13-year-old girls, IAAT at the level of the umbilicus was 24.1 ± 4.1 and 25.7 ± 4.1 cm², respectively (de Ridder et al., 1992a). In a study in 11-year-olds, IAAT was 17.8 ± 10.0 and 24.8 ± 8.8 cm² in boys and girls, respectively (Fox et al., 1993). These values in children and adolescents compare to typical values of 100–120 cm² of IAAT in healthy non-obese adults (Lemieux et al., 1993), although it is difficult to compare absolute levels because of differences in body size.

Total fat mass is an important determinant of IAAT (Lemieux et al., 1993). It is currently unclear whether increasing adiposity in children and adolescents is related to increased deposition of visceral fat. Fox et al. (1993) found that differences in adiposity in obese children are predominately found subcutaneously; in obese versus control adolescents, the majority of excess abdominal adipose tissue was found subcutaneously (353 ± 94 cm² vs. 79 ± 61 cm²), although there was still greater IAAT in the obese children (49 ± 21 cm² vs. 22 ± 11 cm²). It is clear that a portion of the variance in IAAT is explained by total fat mass, although interpretation of findings is complicated by strong multicollinearity among IAAT, SAAT, and total body fat (Goran et al., 1997). In 101 prepubertal children the correlation between IAAT and total fat was 0.81 (Goran et al., 1997), similar to that seen in 206 adult women (Treuth et al., 1995). However, the relationship between IAAT and total body fat was not significant after adjusting for SAAT and there was no relationship between IAAT and percent body fat (Goran et al., 1997). Thus, the relationship between IAAT and body fat may be explained by multicollinearity, and a major portion of the variance in IAAT is independent of total body fat.

RELATIONSHIP BETWEEN ANTHROPOMETRIC INDICES AND IAAT

CT and MRI are accurate imaging techniques for assessing body fat distribution, but the disadvantages are cost, radiation exposure (for CT), and use limited to a research setting. Thus, based on the relationship between visceral fat and anthropometric dimensions, other indirect indicators of body fat distribution have been used. For example, in adults the waist-to-hip ratio or the waist circumference are often used as

markers of IAAT (Després et al., 1991; Poulriot et al., 1994). However, in children (Goran et al., 1995b) and adolescents (de Ridder et al., 1992a; Fox et al., 1993), the correlation between these markers and IAAT as measured by imaging techniques is not strong. In order to identify an accurate alternative index, it is important to review the relationship between visceral fat and anthropometry and body composition.

In young children (Goran et al., 1995b), the waist-to-hip ratio was not significantly correlated with IAAT, whereas individual trunk skinfolds and the ratio of trunk skinfolds to extremity skinfolds explained 62% of the variation in IAAT. In one study of adolescent girls, there were no significant correlations among waist circumference, waist-to-hip ratio or trunk-to-extremity skinfold ratio, and IAAT area as measured by MRI (de Ridder et al., 1992a). Similarly, in 11-year-old boys and girls the waist-to-hip ratio was not significantly correlated with IAAT (Fox et al., 1993). In these studies of adolescents, anthropometric indices explained only 25–50% of the variation in IAAT (Fox et al., 1993; de Ridder et al., 1992a).

In 101 prepubertal Caucasian and African-American children (Goran et al., 1998), the strongest anthropometric correlates of IAAT were the abdominal ($r = 0.88$), subscapular ($r = 0.85$), and suprailiac ($r = 0.85$) skinfolds and waist circumference ($r = 0.84$); the strongest correlates of SAAT were waist circumference ($r = 0.93$) and the triceps ($r = 0.92$), abdominal ($r = 0.91$), suprailiac ($r = 0.91$), and axilla ($r = 0.84$) skinfolds. The correlations between IAAT and SAAT and traditional indices of central fat distribution such as the trunk-to-extremity skinfold ratio ($r = 0.49$ for IAAT; $r = 0.5$ for SAAT) and waist-to-hip ratio ($r = 0.32$ for IAAT; $r = 0.4$ for SAAT) were much lower. In forward multiple regression analysis, the abdominal skinfold, ethnicity, and subscapular skinfold explained 82% of the variance in IAAT; waist circumference, subscapular skinfold, height, and abdominal skinfold explained 92% of the variance in SAAT. Based on this information, prediction equations were developed which accurately estimated IAAT and SAAT, as measured by CT in an independent sample of 12 children (Goran et al., 1998).

The use of DXA to measure total abdominal fat may provide a stronger measure of

visceral fat, but this technique cannot resolve subcutaneous fat from visceral fat. The combination of total abdominal fat by DXA and skinfold/anthropometry data (as an index of subcutaneous fat) has been used in adults to estimate IAAT with reasonable accuracy (Svendsen et al., 1993; Treuth et al., 1995). One study explored the combination of DXA and skinfolds to estimate visceral fat in children (Goran et al., 1998). In 101 prepubertal children, the combination of trunk fat by DXA, total fat by DXA, and abdominal skinfold thickness predicted IAAT as measured with CT scanning with a model R^2 of 0.85 and a standard error of the estimate of ± 9 cm² (Goran et al., 1998). However, this approach only marginally improved the prediction power of the anthropometric equation using the abdominal skinfold, ethnicity (Caucasian vs. African-American) and subscapular skinfold (model R^2 of 0.82 and a standard error of the estimate of ± 10 cm²).

In summary, combinations of skinfolds and circumferences can be modeled to yield relatively accurate estimates of IAAT and SAAT in the absence of direct measurement by imaging techniques. The addition of regional measures of trunk fat by DXA only marginally improves the prediction of visceral fat.

INFLUENCE OF ETHNICITY ON IAAT

Ethnic background affects fat distribution in children (Greaves et al., 1989; Goran et al., 1995a). It has long been known that African-American and Mexican-American children and adults have greater skinfold thicknesses in the central region (Greaves et al., 1989). When Mohawk Indian children were matched in total body fat content to a group of Caucasian children (using bioelectrical impedance to estimate body composition), subcutaneous fat (by skinfold) was more centrally distributed in the Mohawk children (Goran et al., 1995a).

Since most prior studies of ethnic differences in fat distribution have been limited to skinfolds, it is unknown whether the findings represent differences in SAAT or IAAT. In 18 obese, adult females (Conway et al., 1995), African-Americans had significantly lower IAAT than Caucasians (105 ± 25 vs. 160 ± 70 cm²), even though the two groups were matched for age, weight, and total body fat. In non-obese girls (7–10 years), Yanovski et al (1996) showed a lower absolute

IAAT in African-Americans ($n = 21$) compared to Caucasians ($n = 23$), although the difference was not significant when expressed relative to total body fat. In 101 Caucasian and African-American obese and non-obese boys and girls, the regression slope between IAAT and SAAT was significantly lower in African-Americans compared to Caucasians (0.17 ± 0.02 vs. 0.23 ± 0.02 cm² of IAAT per cm² of SAAT). Although limited to a cross-sectional analysis, this finding suggests that the rate of accumulation of IAAT relative to SAAT is 26% lower in African-American than in Caucasian children (Goran et al., 1997). Thus, the suggestion of increased central fat in different ethnic groups using skinfolds is not supported by direct measurement of visceral fat, which shows a lower accumulation in African-Americans early in life. The lower visceral fat in African-American children occurs across the spectrum of fatness and is similar between sexes. In addition, the ethnic difference in visceral fat may be due to a differential partitioning of adipose tissue within the abdominal region, with African-Americans depositing more fat subcutaneously. However, the important issue (in terms of health risk) is whether ethnicity influences the strength and/or magnitude of the relationships between IAAT and the subsequent development of disease risk factors (see Gower, 1999).

INFLUENCE OF GENDER ON IAAT

There are sex differences in intra-abdominal adipose tissue area in adults (Lemieux et al., 1993). Males have greater amounts than females, even after taking differences in total body fat into account. This difference is also apparent during adolescence (Fox et al., 1993), but not in prepubescent children (Goran et al., 1997). Since sex hormones are known to affect regional fat deposition (Björntorp et al., 1990), hormonal environment may contribute to sex differences in fat distribution that emerge after adolescence (de Ridder et al., 1992b). The hormonal environment plays a key role in determining body fat distribution; this has been reviewed recently (Björntorp, 1996) and is discussed in more detail by Rommich and Rogol (1999).

INFLUENCE OF DIETARY FACTORS ON IAAT

The influence of dietary factors on visceral fat accumulation has not been exten-

sively studied in children or adults. One study in Caucasian, healthy, non-obese adult males ($n = 135$; 44 ± 10 years; $23 \pm 8\%$ body fat) and females ($n = 214$; 45 ± 14 years; $33 \pm 10\%$ body fat) examined the relationships between CT measures of IAAT and SAAT and dietary factors (Larson et al., 1996). Fat intake only explained 2% of the variance in general adiposity after adjusting for fat-free mass, age, gender, physical activity, and nonfat intake. Dietary fat accounted for only 1.4% of the variance in SAAT (although this effect disappeared after adjusting for age, gender, and physical activity) and none of the variance in IAAT before or after adjustment (Larson et al., 1996). Thus, in agreement with other studies (reviewed by Lissner and Heitmann, 1995), dietary fat appears to play a minor role in general adiposity and is not cross-sectionally related to visceral fat (Larson et al., 1996).

Several cross-sectional studies in children have described a small, but significant, positive relationship between dietary fat intake and body fat mass (Maffeis et al., 1996; Gazzaniga and Burns, 1993; Nguyen et al., 1996). In addition, previous cross-sectional studies support a relationship between dietary fat components and blood lipids in children (Glueck et al., 1982). In addition to dietary factors, body fat / fat distribution is also known to be associated with risk factors for cardiovascular disease. Some studies have shown that fat distribution, especially central body fat, is more closely related to cardiovascular risk than total body fat mass in adults (Walton et al., 1995; Williams et al., 1997). However, the interrelationships between these three important factors (dietary fat, body fat / fat distribution, and blood lipids) has not been thoroughly examined in children. Thus, for example, it is not known whether dietary fat has a direct influence on cardiovascular risk factors or whether this relationship is mediated by body fat / fat distribution.

Published studies that have examined the link between diet and regional adiposity in children and adolescents using direct measures of visceral fat are apparently not available. Ku et al. (1998) examined the relationships between dietary fat, body fat and fat distribution, and blood lipids in 66 prepubertal children (45 African-American and 21 Caucasian, 4–10 years). It was hy-

pothesized that dietary fat would be associated with serum lipid profile independent of ethnicity, body fat, and fat distribution. Dietary total fat, saturated fat, monounsaturated fat, and polyunsaturated fat were estimated by averaging two 24-hour dietary recalls. Fasting serum triacylglycerol, total cholesterol, and high-density lipoprotein cholesterol (HDL-C) were analyzed and low-density lipoprotein cholesterol (LDL-C) was calculated by the method of Friedewald. Body composition and fat distribution were measured by dual-energy X-ray absorptiometry and computed tomography.

African-American children consumed more energy from total fat (35.3 vs. 31.5%, $P < 0.05$), saturated fat (13.7 vs. 12.2%, $P < 0.05$), protein (16.4 vs. 13.2%, $P = 0.02$), and less from carbohydrate (48 vs. 57.1%, $P < 0.01$) than Caucasian children. There were no significant correlations between dietary fat and body fat / fat distribution indices after adjusting for nonfat energy intake and total lean tissue mass. Total body fat ($r = 0.32$), SAAT ($r = 0.39$), and IAAT ($r = 0.42$) were all positively related to serum triglyceride concentration. These associations remained significant in a multiple linear regression model in which body fat indices were adjusted for ethnicity, total lean tissue, dietary total fat, and nonfat intake. The results suggest that body fat / fat distribution may play a more important role than dietary fat in the course of cardiovascular risk development in prepubertal children. It is important to note that ethnicity, adiposity, fat distribution and dietary intake together accounted for only ~20% of the variance in serum triacylglycerol in this study, suggesting that other factors may be involved in the interrelationships between dietary fat, body fat, fat distribution, and blood lipids.

CHANGES IN IAAT DURING GROWTH IN CHILDREN

There are no published data that have examined longitudinal changes in IAAT in children during growth and maturation. Therefore, for the purposes of this review, findings in a preliminary format on dynamic changes in visceral fat during childhood growth are presented. IAAT, SAAT, total body fat mass, and anthropometry were measured annually for 3 years in 29 African-American children using techniques identical to that previously described (Go-

TABLE 1. Rate of change in fat distribution and body composition in 29 African-American children over 2 years

Variable	Mean \pm SD	Range
IAAT (cm ² /year)	4.3 \pm 7.3	-6.5 to 24.4
SAAT (cm ² /year)	28.0 \pm 33.4	-37.0 to 124.1
Fat mass (kg/year)	1.5 \pm 2.4	-1.2 to 7.3
Fat-free mass (kg/year)	3.9 \pm 1.4	1.4 to 7.7

IAAT is intra-abdominal adipose tissue and SAAT is subcutaneous abdominal adipose tissue by CT scanning; fat mass and fat-free mass were estimated by dual energy X-ray absorptiometry.

ran et al., 1997). At the onset of the study, the mean characteristics of the sample were: 7.6 \pm 1.7 years of age, 33.1 \pm 11.9 kg in body weight, 26.7 \pm 18.1 cm² of IAAT, 84.0 \pm 80.2 cm² of SAAT, 10.7 \pm 7.25 kg of body fat, and 20.7 \pm 4.9 kg of fat-free mass. All children were defined as prepubertal at the onset of the study based on clinical examination.

The mean rate of change in IAAT, SAAT, fat mass, and fat-free mass was determined by regression of each of the three measures over time against age in years at the time of the measurement. There was a wide range in the rate of change of all body composition / fat distribution parameters (Table 1). The rate of change in IAAT was significantly correlated with both the rate of change in SAAT ($r = 0.70$) and the rate of change in body fat mass ($r = 0.73$) (Fig. 1). The rate of change in IAAT was not significantly correlated with the rate of change in fat-free mass. The rate of change in IAAT was 0.153 cm² per cm² of SAAT (similar to that estimated from the cross-sectional relationship at baseline) and 2.22 cm² per kg of fat mass. The rate of change in IAAT was similar in boys and girls (5.7 \pm 2.3 vs. 3.6 \pm 1.7 cm²/year; mean \pm SE) and among those children remaining prepubertal ($n = 13$) compared to those who entered puberty ($n = 12$) after 2 years of follow-up (4.6 \pm 2.1 vs. 5.6 \pm 2.1 cm²/year; mean \pm SE). Interestingly, IAAT did not change significantly in the remaining small group of four children who were more advanced in pubertal status after 2 years of follow-up.

These preliminary results verify that the linear acquisition of IAAT during growth occurs as a function of SAAT and total fat mass accumulation. Further studies in larger and more diverse samples are needed to fully define the dynamics of this process, and understand to the interrelationships of the role of modifiable versus nonmodifiable

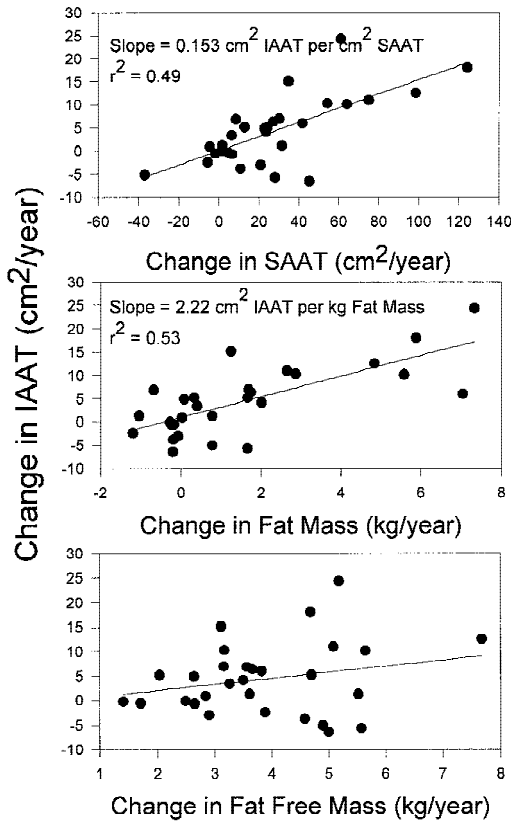


Fig. 1. Relationship between rate of change in IAAT and rate of change in SAAT and total fat mass in 29 African-American children. The rate of change in IAAT, SAAT, and fat mass was determined by regression of three annual measures over time against age in years at the time of the measurement. IAAT and SAAT were determined by computed tomography; fat mass was determined by dual energy X-ray absorptiometry.

factors in influencing change in IAAT, SAAT, and total fatness during childhood growth and maturation.

LITERATURE CITED

- Björntorp P. 1996. The regulation of adipose tissue distribution in humans. *Int J Obes* 20:291–302.
- Björntorp P, Ottosson M, Rebuffe-Scrive M, Xu X. 1990. Regional obesity and steroid hormone interactions in human adipose tissue. In: Bray G, Ricquier D, Spiegelman B, editors. *Obesity: towards a molecular approach*. New York: Alan R. Liss. p 147–157.
- Caprio S. 1999. Relationship between abdominal visceral fat and metabolic risk factors in obese adolescents. *Am J Hum Biol* 11:259–266.
- Chowdhury B, Sjostrom L, Alpsten M, Kostanty J, Kvist H, Lofgren R. 1994. A multi-compartment body composition technique based on computed tomography. *Int J Obes* 18:219–234.
- Conway JM, Yanovski SZ, Avila NA, Hubbard VS. 1995. Visceral adipose tissue differences in black and white women. *Am J Clin Nutr* 61:765–771.
- de Ridder CM, de Boer RW, Seidell JC et al. 1992a. Body fat distribution in pubertal girls quantified by magnetic resonance imaging. *Int J Obes* 16:443–449.
- de Ridder CM, Thijssen JHH, Bruning PF, Van den Brande JL, Zonderland ML, Erich WBM. 1992b. Body fat mass, body fat distribution, and pubertal development: a longitudinal study of physical and hormonal sexual maturation of girls. *J Clin Endocrinol Metab* 75:442–446.
- Després J-P, Prud'homme D, Pouliot M-C, Tremblay A, Bouchard C. 1991. Estimation of deep abdominal adipose-tissue accumulation from simple anthropometric measurements in men. *Am J Clin Nutr* 54:471–477.
- Fox K, Peters D, Armstrong N, Sharpe P, Bell M. 1993. Abdominal fat deposition in 11-year-old children. *Int J Obes* 17:11–16.
- Gazzaniga JM, Burns TL. 1993. Relationship between diet composition and body fatness, with adjustment for resting energy expenditure and physical activity, in preadolescent children. *Am J Clin Nutr* 58:21–28.
- Glueck CJ, Waldman G, McClish DK et al. 1982. Relationships of nutrient intake to lipids and lipoproteins in 1234 White children: the Lipid Research Clinics Prevalence Study. *Arteriosclerosis* 2:523–536.
- Goran MI, Kaskoun MC, Martinez C, Kelly B, Carpenter WH, Hood VL. 1995a. Energy expenditure and body fat distribution in Mohawk Indian children. *Pediatrics* 95:89–95.
- Goran MI, Kaskoun MC, Shuman WP. 1995b. Intra-abdominal adipose tissue in young children. *Int J Obes* 19:279–283.
- Goran MI, Nagy TR, Treuth MT et al. 1997. Visceral fat in Caucasian and African-American pre-pubertal children. *Am J Clin Nutr* 65:1703–1709.
- Goran MI, Gower BA, Treuth MT, Nagy TR. 1998. Prediction of visceral fat from body composition and anthropometry in pre-pubertal Caucasian and African American children. *Int J Obes* 22:549–558.
- Gower BA. 1999. Syndrome X in Children: influence of ethnicity and visceral fat. *Am J Hum Biol* (in press).
- Greaves KA, Puhl J, Baranowski T, Gruben D, Seale D. 1989. Ethnic differences in anthropometric characteristics of young children and their parents. *Hum Biol* 61(3):459–477.
- Gutin B, Owens S. 1999. Role of exercise intervention in improving body fat distribution and risk profile in children. *Am J Hum Biol* 11:237–247.
- Katzmaryk PT, Pérusse L, Bouchard C. 1999. Genetics of abdominal visceral fat levels. *Am J Hum Biol* 11:225–235.
- Ku C-Y, Gower BA, Nagy TR, Goran MI. 1998. Relationships between dietary fat, body fat, and serum lipids in pre-pubertal children. *Obes Res* 6:400–407.
- Larson DE, Hunter GR, Williams MJ, Kekes-Szabo T, Nyikos I, Goran MI. 1996. Dietary fat in relation to body fat and intraabdominal adipose tissue: A cross-sectional study. *Am J Clin Nutr* 64:677–684.
- Lemieux S, Prud'homme D, Bouchard C, Tremblay A, Després J-P. 1993. Sex differences in the relation of visceral adipose tissue accumulation to total body fatness. *Am J Clin Nutr* 58:463–467.
- Lissner L, Heitmann BL. 1995. Dietary fat and obesity: Evidence from epidemiology. *Eur J Clin Nutr* 49:79–90.
- Maffei C, Pinell L, Schutz Y. 1996. Fat intake and adiposity in 8 to 11-year-old obese children. *Int J Obes* 20:170–174.
- Malina RM, Koziel S, Bielicki T. 1999. Variation in sub-

- cutaneous adipose tissue distribution associated with age, sex, and maturation. *Am J Hum Biol* 11:189–200.
- Nguyen VT, Larson DE, Johnson RK, Goran MI. 1996. Fat intake and adiposity in children of lean and obese parents. *Am J Clin Nutr* 63:507–513.
- Pouliot M-C, Després J-P, Lemieux S et al. 1994. Waist circumference and abdominal sagittal diameter: Best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol* 73:460–468.
- Roemmich JN, Rogol AD. 1999. Hormonal changes during puberty and their relationship to fat distribution. *Am J Hum Biol* 11:209–224.
- Svendson OL, Hassager C, Bergmann I, Christiansen C. 1993. Measurement of abdominal and intra-abdominal fat in postmenopausal women by dual energy x-ray absorptiometry and anthropometry: Comparison with computerized tomography. *Int J Obes* 17:45–51.
- Treuth MS, Hunter GR, Kekes-Szabo T. 1995. Estimating intra-abdominal adipose tissue by dual energy X-ray absorptiometry. *Am J Clin Nutr* 62:527–531.
- Walton C, Lees B, Crook D, Worthington M, Godsland IF, Stevenson JC. 1995. Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age. *Am J Med* 99:459–464.
- Williams MJ, Hunter GR, Szabo TK, Snyder S, Treuth MS. 1997. Regional fat distribution in women and risk of cardiovascular disease. *Am J Clin Nutr* 65:855–860.
- Yanovski JA, Yanovski SZ, Filmer KM et al. 1996. Differences in body composition of Black and White girls. *Am J Clin Nutr* 64:833–839.