BMI: How does it measure up?

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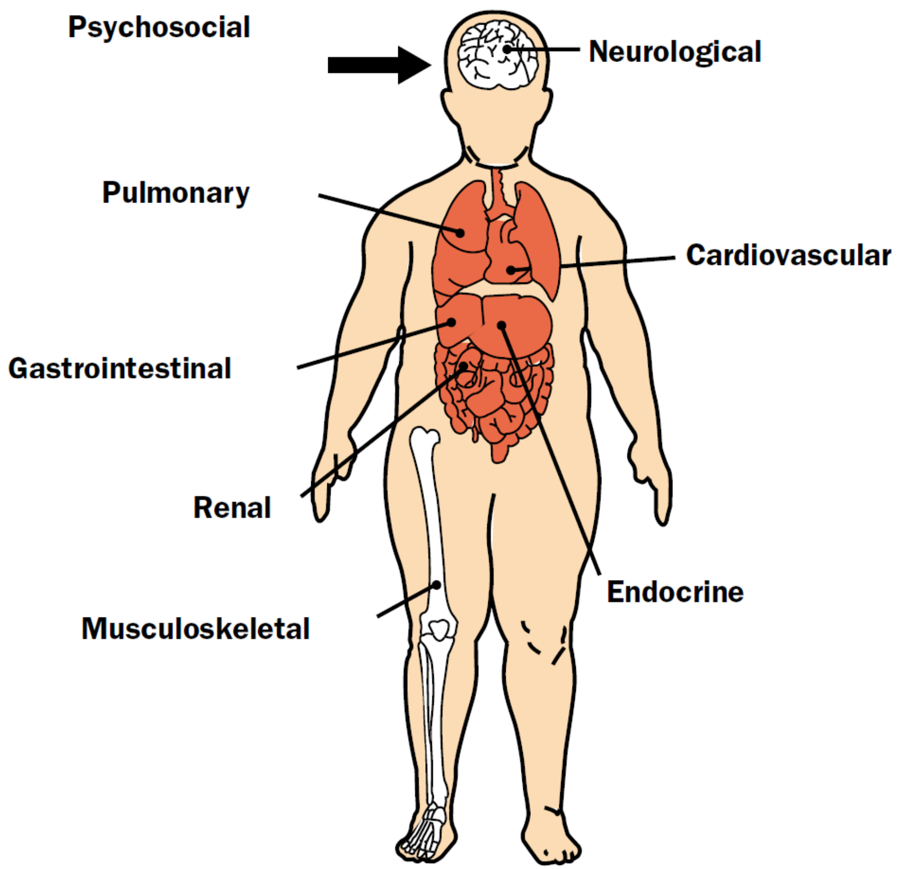
Disclosures

- None

Overview

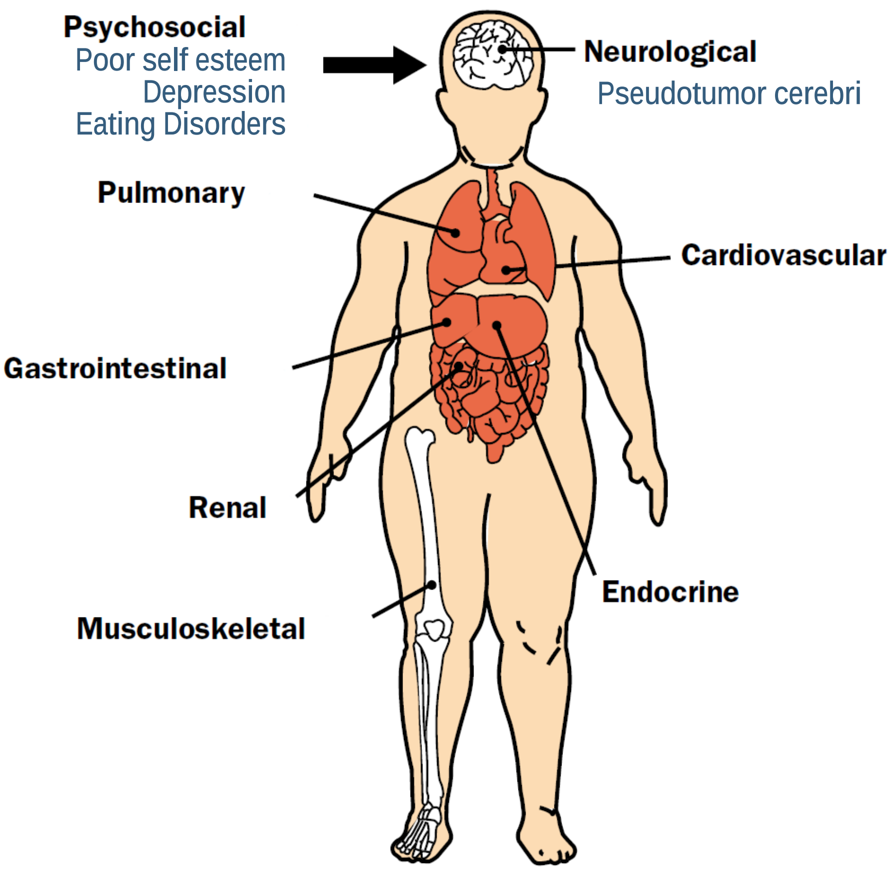
- Health consequences of childhood obesity
- Methods available for assessing excess adiposity
- Best method to screen for complications of obesity

Complications of Childhood Obesity



http://www.mozartinshape.org/misvsobesity/whymis.php?id=ch02, accessed 6/26/15

Complications of Childhood Obesity



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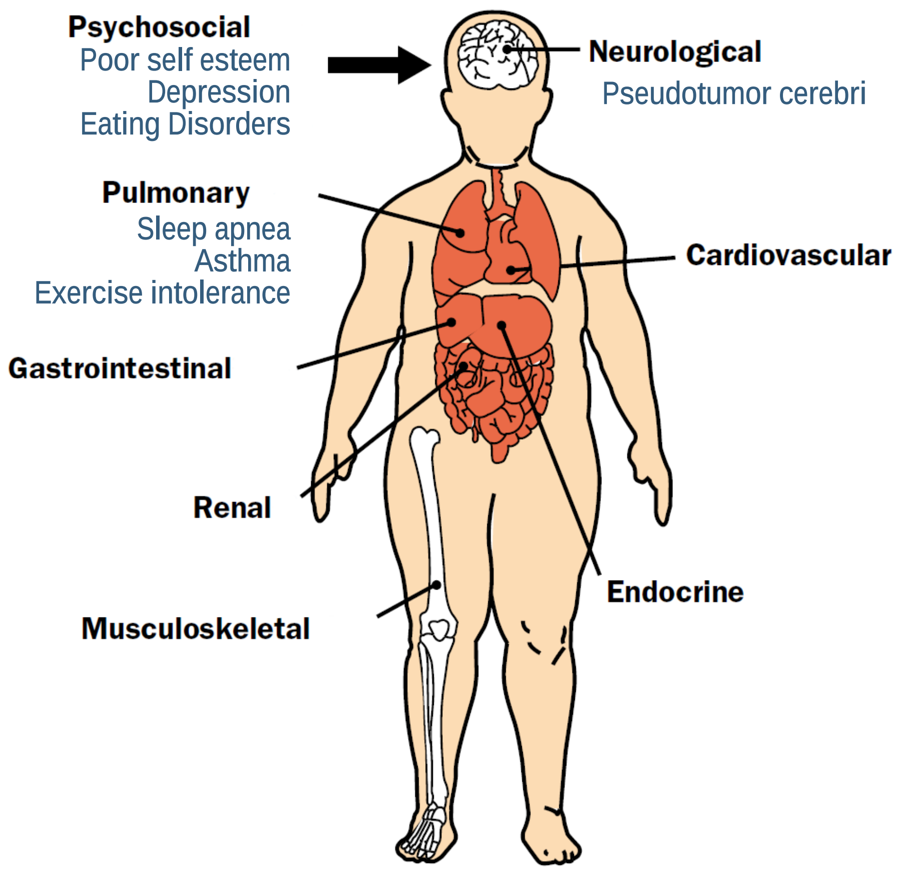
Complications of Childhood Obesity



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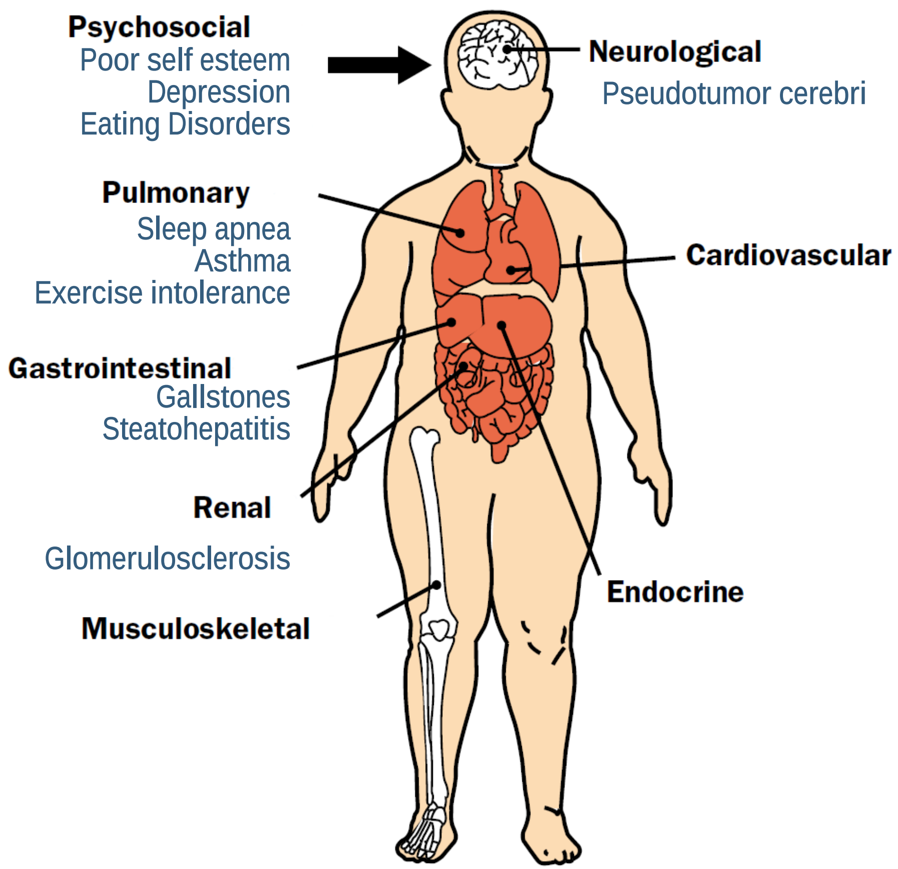

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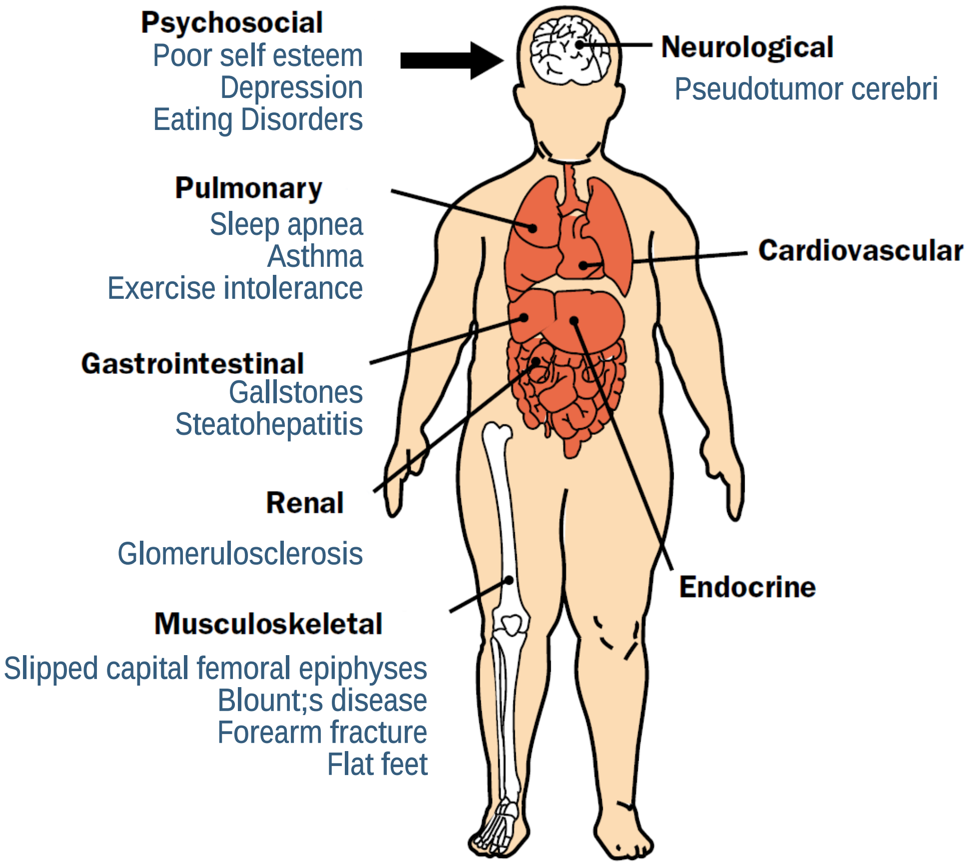

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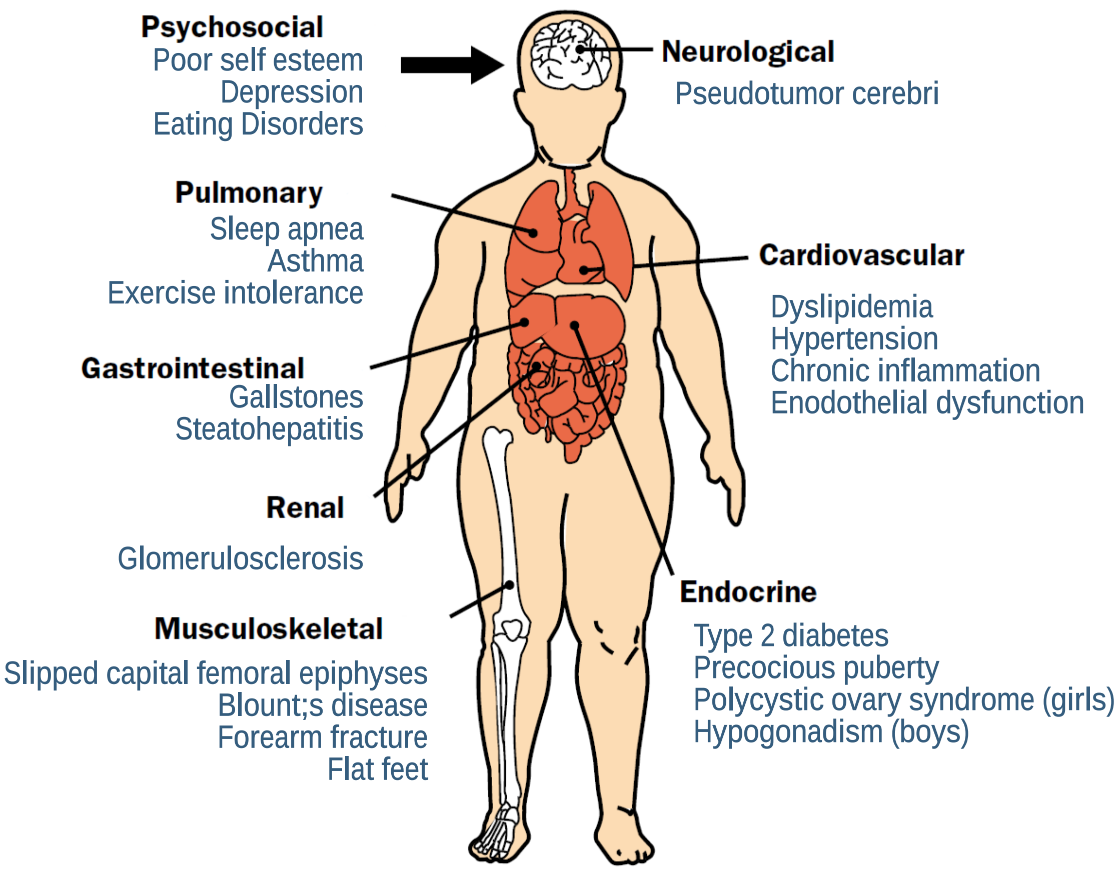
Complications of Childhood Obesity



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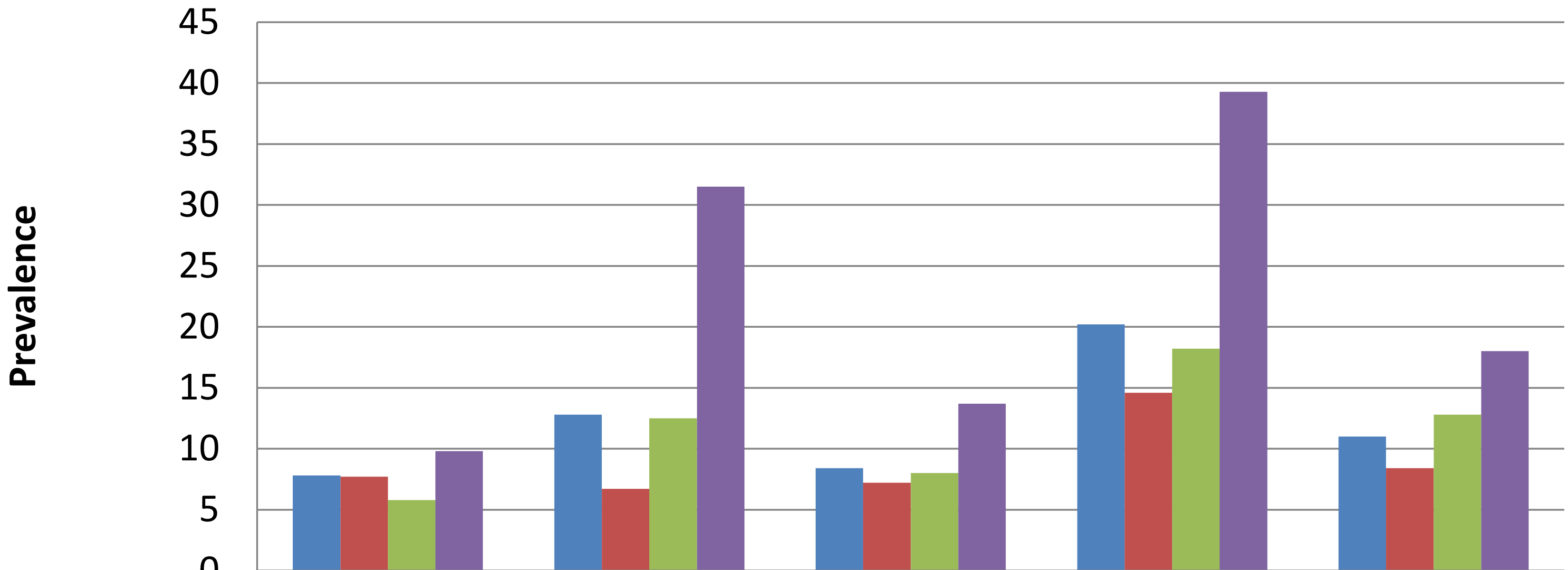
Prevalence of dyslipidemia and borderline high or high BP in children 2011-2012 (NHANES)



	TC≥200	HDL-C <40mg/dL	Non-HDL-C ≥145 mg/dL	Dyslipidemia	Borderline Hi or High BP
Total	7.8	12.8	8.4	20.2	11
Normal	7.7	6.7	7.2	14.6	8.4
Overweight	5.8	12.5	8	18.2	12.8
Obese	9.8	31.5	13.7	39.3	18

Adapted from Kit et al. JAMA Pediatrics 2015

Complications of Childhood Obesity

What is the best way to identify excess adiposity?

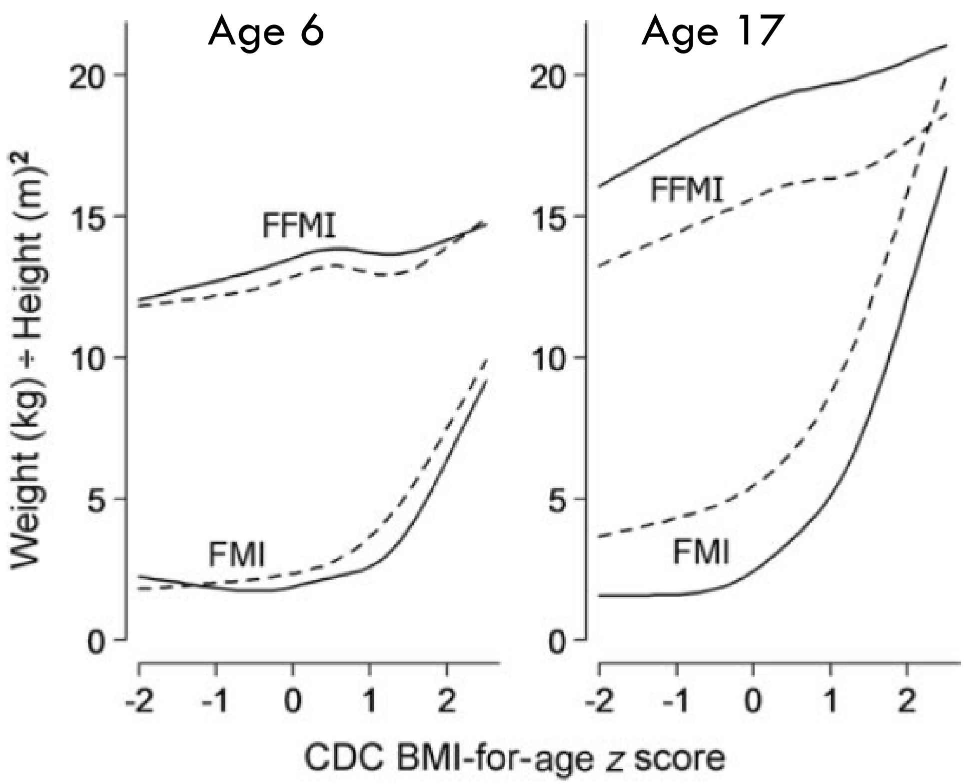
What is the best way to identify those at greatest risk of health complications of obesity?

http://uploads7.wikiart.org/images/fernando-botero/family-scene.jpg

Assessing excess adiposity

- BMI is most widely used screening tool
  - Height and weight measures are relatively easy to obtain
  - Requires minimal skill, equipment, space to acquire measurements
  - Excellent reference data to define overweight and obesity
  - Useful at all levels (population, clinic, research, etc)

High BMI is a good indicator of excess adiposity

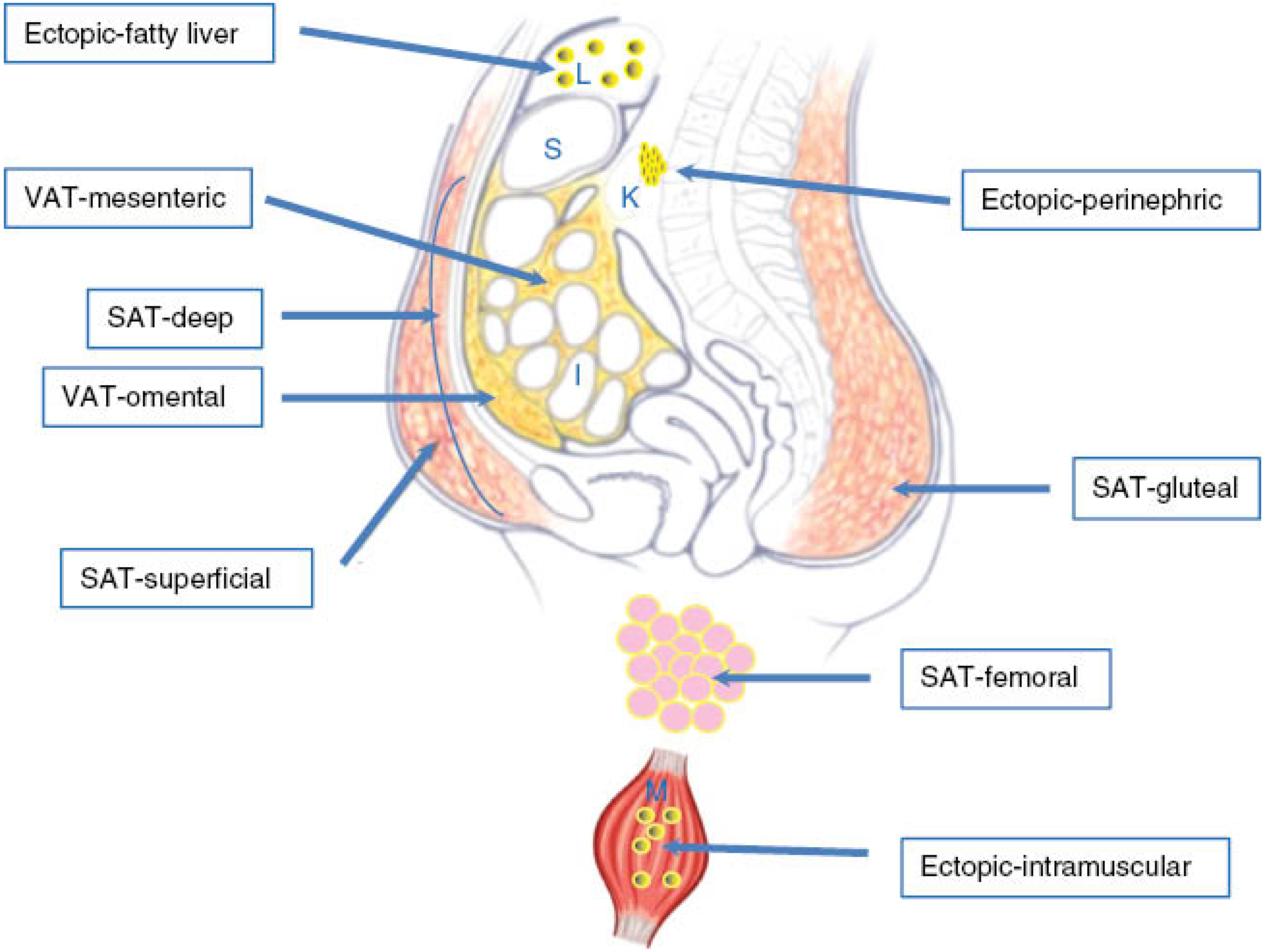


Fat mass index and fat free mass index according to BMI-for-age z score in the Pediatric Rosetta Study (n=1186)
Solid lines represent boys, and the dashed lines represent girls
From Freedman and Sherry Pediatrics 2009;124:S23–S34

Assessing excess adiposity

- Limitations of BMI
  - Doesn’t distinguish between fat and lean mass
  - Doesn’t measure fat distribution – “harmful fat”

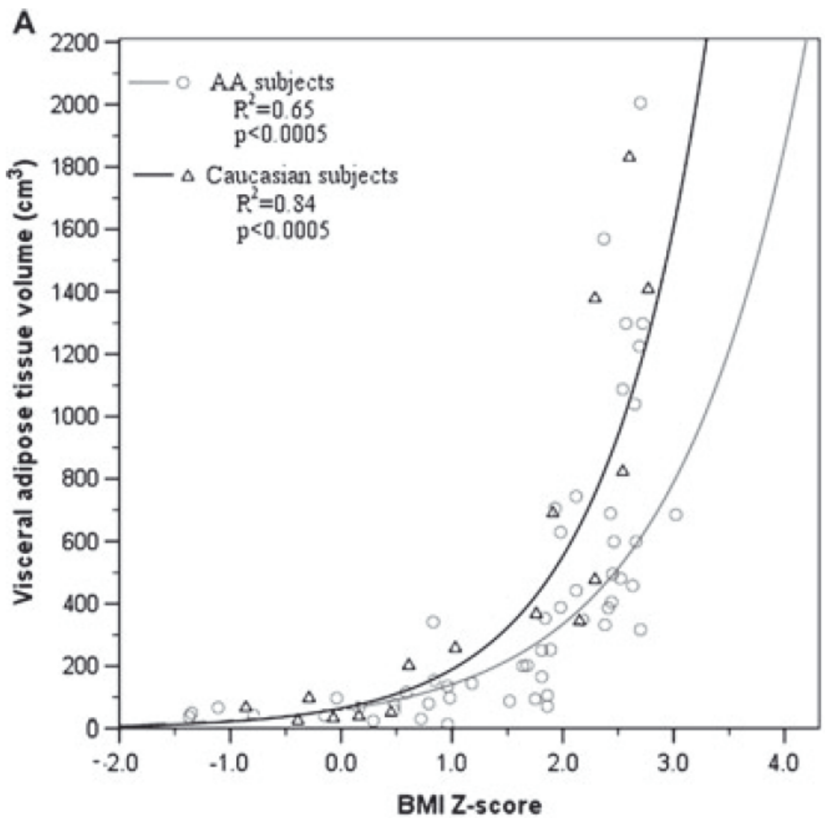
Not all fat is created equal



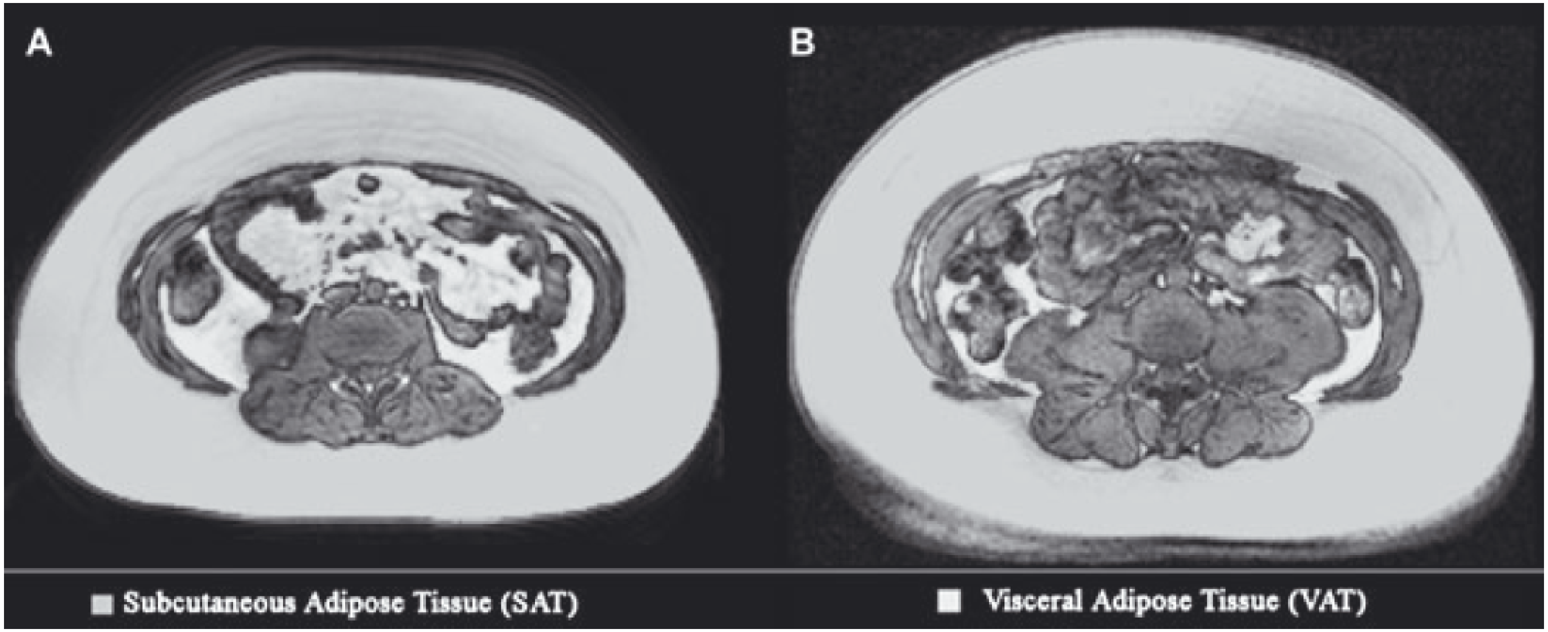
http://www.degruyter.com/view/j/hmbci.2014.19.issue-1/hmbci-2014-0023/graphic/hmbci-2014-0023_fig1.jpg

Visceral vs subcutaneous fat

- Koren et al. *Pediatric Diabetes 2013: 14: 575–584.*
- 28 normal weight and 44 obese adolescents
- Visceral adipose tissue volume increases exponentially as BMI increases



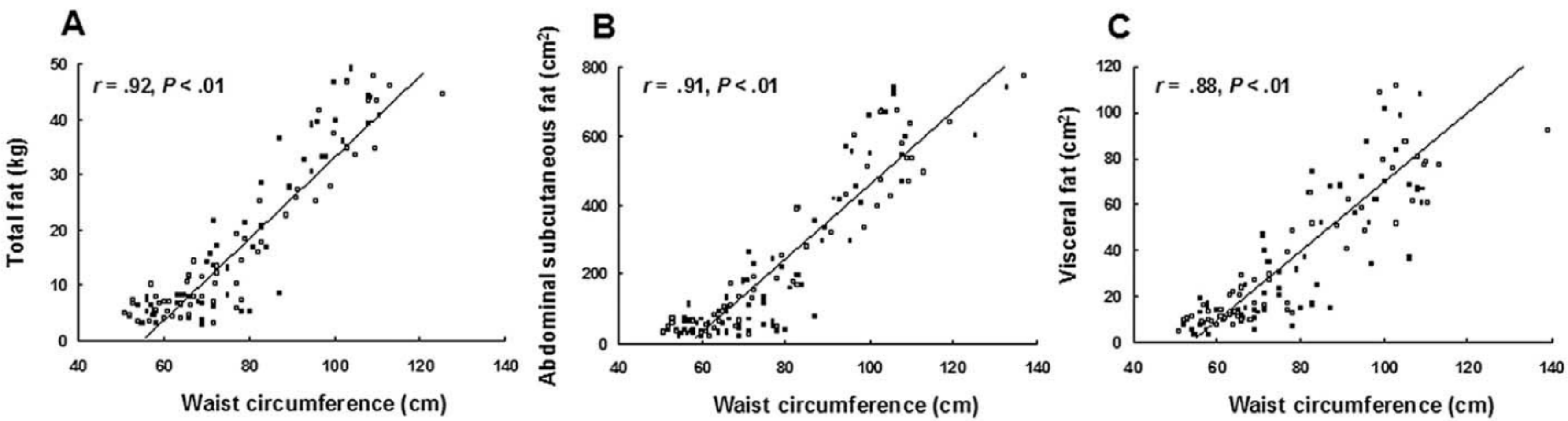
Visceral vs subcutaneous fat



Fat partitioning patterns [transverse magnetic resonance imaging (MRI) slices (L2–L3)] in obese Caucasian (A) and African-American (B) females. Demographics: (A) 14.3-yr old, Tanner 4, body mass index (BMI) 34.7, and BMI Z-score 2.29. (B) 14.8-yr old, Tanner 4, BMI 37.2, and BMI Z-score 2.43. From Koren et al. *Pediatric Diabetes 2013: 14: 575–584.*

Waist circumference and visceral fat

- Waist circumference correlates well with cross-sectional measures of total fat, subcutaneous fat and visceral fat in 145 children, ages 8 to 17y
- From Lee et al. J Pediatr 2006;148:188-94



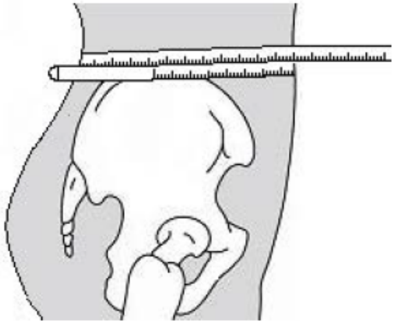
Waist Circumference

- Surrogate marker of visceral adiposity
- Doesn't distinguish between subcutaneous and intra-abdominal fat depots
- Measurement issues
  - Modesty
  - Different measurement protocols

http://i.dailymail.co.uk/i/pix/2014/10/17/1413543416710_wps_21_image001_png.jpg

Waist circumference measurement sites

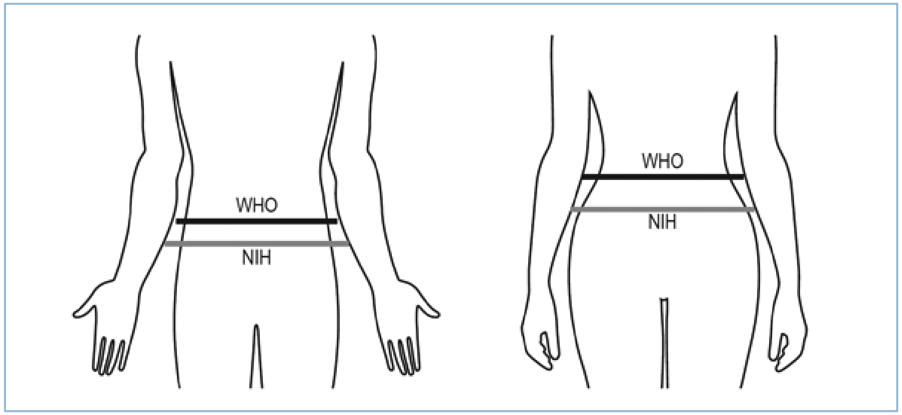
- NHANES: top of the iliac crest
  - Requires palpation
  - Landmark can be difficult to find in obese children
  - Not a natural minimum, so tape measure can be difficult to place on the body contour



NHANES Anthropometry Procedures Manual Jan 2011, p 3-20

Waist circumference measurement sites

- NHANES: top of the iliac crest
- WHO: midpoint between the last palpable rib and top of the iliac crest
  - Requires palpation
  - Difficult landmarks to identify in obese children



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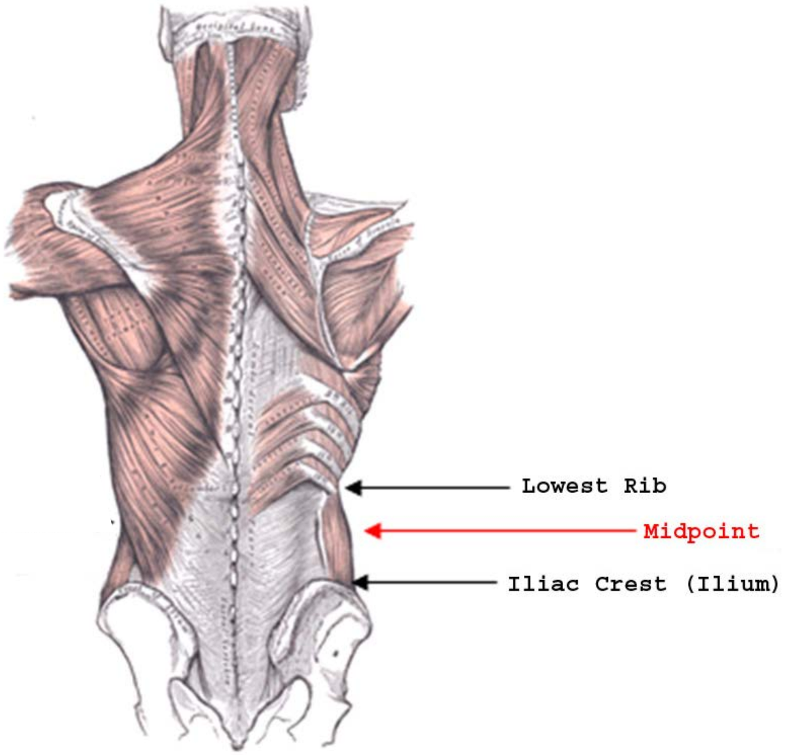
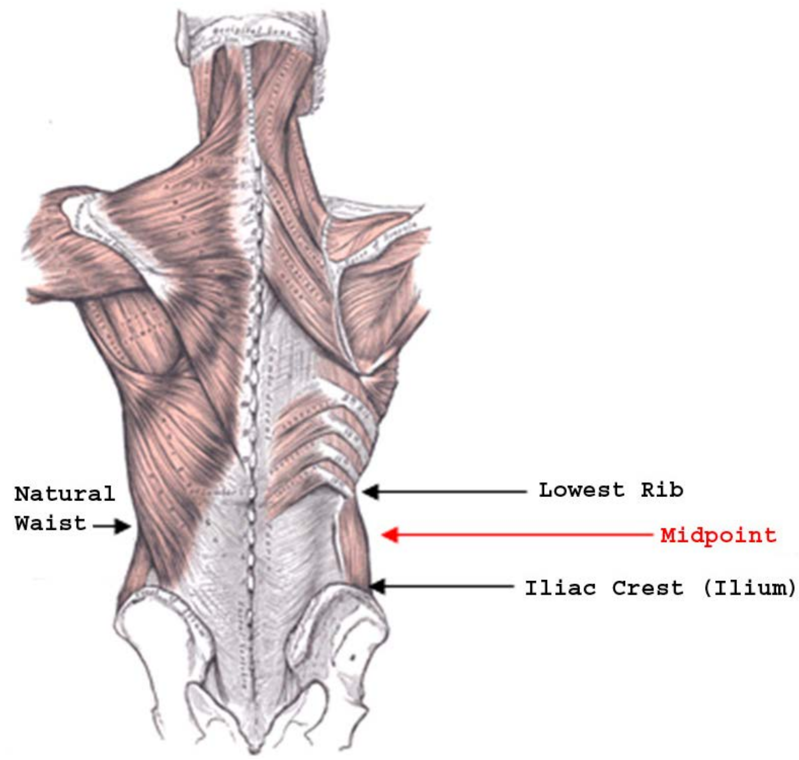


https://www.phenxtoolkit.org/toolkit_content/web/anthropometrics/Waist_Circumference_Exhibit1_1.jpg

Waist circumference measurement sites

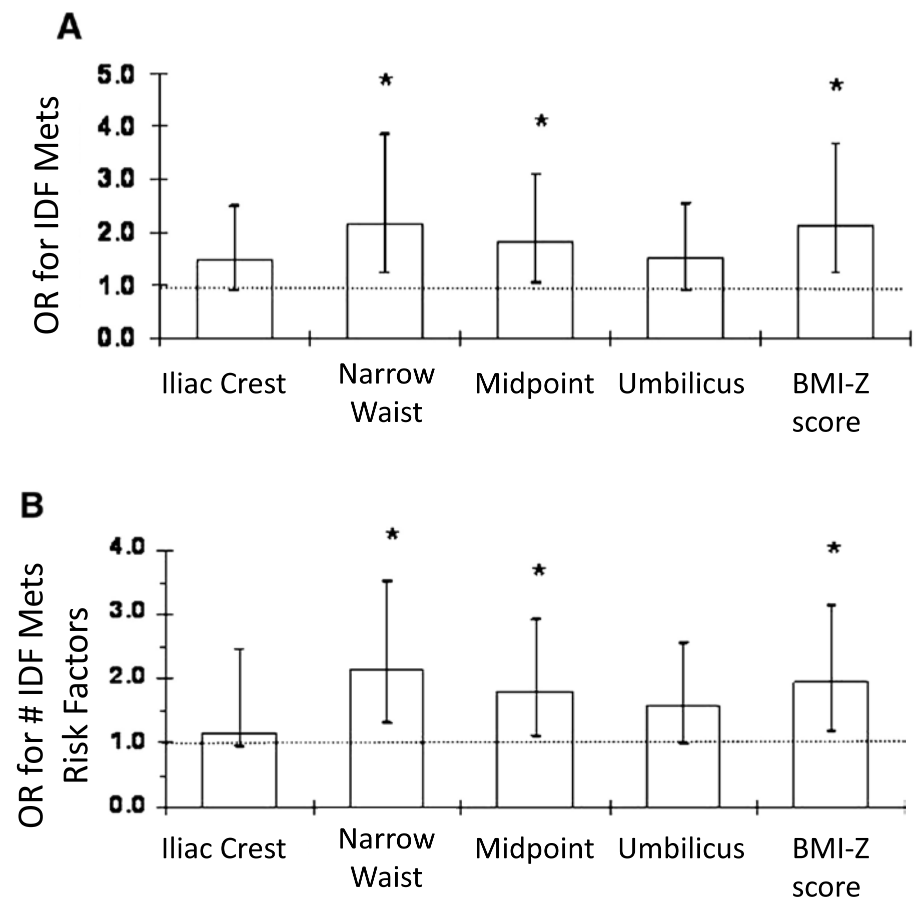
- NHANES: top of the iliac crest
- WHO: midpoint between the last palpable rib and top of the iliac crest
  - Requires palpation
  - Difficult landmarks to identify in obese children
- Natural waist (minimum)
- NIH Multi-Ethnic Study of Atherosclerosis (MESA) study: level of the umbilicus or navel



https://www.phenxtoolkit.org/toolkit_content/web/anthropometrics/Waist_Circumference_Exhibit1_1.jpg

Which is the best waist circumference measurement site?

- Johnson et al. 2010 compared waist circ. site to MetS and risk factors
  - fasting insulin, glucose, cholesterol level, BP
- 73 overweight and obese children, 8 to 17 years of age
- Narrow waist and mid-point had greatest odds ratio for metabolic syndrome and risk factors



Johnson et al. J Peds 156(2): 247-252, 2010. Association of waist circumference and BMI z-score with (A) Metabolic Syndrome; and (B) # of risk factors.*P < .05

Waist circumference vs BMI in predicting insulin resistance

Model number	Independent Variable	Beta	SE	p	R^2	Model number		Beta	SE	p	R^2
1	Age	-0.023	0.018	0.207		1	Age	-0.023	0.018	0.207	
	Gender	-0.024	0.051	0.640			Gender	-0.024	0.051	0.640	
	Race	0.118	0.051	0.022			Race	0.118	0.051	0.022	
	Pubertal Status	-0.258	0.085	0.003	0.22		Pubertal status	-0.258	0.085	0.003	0.22
2	BMI percentile	-0.251	0.065	<.001	0.30	2	WC	-2.413	0.249	<.001	0.55
3	BMI percentile	0.118	0.067	0.080		3	WC and	-2.772	0.320	<.001	
	and WC	-2.772	0.320	<.001	0.56		BMI Percentile	0.118	0.067	0.080	0.56

145 normal and obese children, ages 8 to 17y (Lee et al. J Pediatr 2006;148:188-94)

Waist to Height Ratio vs BMI

Table 2 Odds Ratios and 95% CI for adverse levels of cardiometabolic risk factor variables in normal weight and overweight/obese children: The Bogalusa Heart Study

	NORMAL WEIGHT (n = 2581) (BMI- 5th to 85th percentiles)# (Referenced to waist-to-height ratio <0.5)		
Independent Variable (Top tertile vs. rest)*	**OR**	**95% CI**	**p-value**
Mean Arterial Pressure (mm Hg)	1.30	0.92-1.83	0.13
LDL Cholesterol (mg/dl)	1.66	1.18-2.32	0.003
Triglycerides (mg/dl)	1.47	1.02-2.11	0.03
HDL Cholesterol (mg/dl)	2.01	1.44-2.79	<0.0001
Glucose (mg/dl)	1.13	0.77-1.66	0.51
Insulin (μU/ml)	2.05	1.16-3.62	0.01
Insulin Resistance Index (HOMA-IR)	1.43	0.78-2.62	0.23

*Bottom tertile vs. the rest for HDL cholesterol. Tertiles were age-, race- and sex-specific. Models were age-, race- and sex-adjusted. All variables were included in both the models.

BMI percentiles were age-, race- and sex-specific.

HOMA-IR = Homeostasis model assessment of insulin resistance; CI = Confidence Intervals.

Among normal weight, those with high WHtR had increased odds of CMR risk

From: Mokha et al. BMC Pediatrics 2010, 10:73

Waist to Height Ratio vs BMI

Table 2 Odds Ratios and 95% CI for adverse levels of cardiometabolic risk factor variables in normal weight and overweight/obese children: The Bogalusa Heart Study

	NORMAL WEIGHT (n = 2581) (BMI- 5th to 85th percentiles)# (Referenced to waist-to-height ratio <0.5)			OVERWEIGHT/OBESE (n = 510) (BMI ≥ 85th percentile)# (Referenced to waist-to-height ratio ≥0.5)		
Independent Variable (Top tertile vs. rest)*	**OR**	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**
Mean Arterial Pressure (mm Hg)	1.30	0.92-1.83	0.13	1.10	0.60-2.03	0.75
LDL Cholesterol (mg/dl)	1.66	1.18-2.32	0.003	0.61	0.34-1.10	0.10
Triglycerides (mg/dl)	1.47	1.02-2.11	0.03	0.59	0.32-1.07	0.08
HDL Cholesterol (mg/dl)	2.01	1.44-2.79	<0.0001	0.53	0.30-0.96	0.03
Glucose (mg/dl)	1.13	0.77-1.66	0.51	1.44	0.78-2.67	0.23
Insulin (μU/ml)	2.05	1.16-3.62	0.01	2.09	0.59-7.38	0.24
Insulin Resistance Index (HOMA-IR)	1.43	0.78-2.62	0.23	0.27	0.08-0.90	0.03

*Bottom tertile vs. the rest for HDL cholesterol. Tertiles were age-, race- and sex-specific. Models were age-, race- and sex-adjusted. All variables were included in both the models.

BMI percentiles were age-, race- and sex-specific.

HOMA-IR = Homeostasis model assessment of insulin resistance; CI = Confidence Intervals.

Among normal weight, those with high WHtR had increased odds of CMR risk
Among Overwt/Obese, those with low WHtR had reduced odds of CMR risk

From: Mokha et al. BMC Pediatrics 2010, 10:73

Waist vs BMI as long term predictors of risk

- Garnett et al. Am J Clin Nutr 2007;86:549 –55.
- 342 children measured at age 8 y and a subset of 290 were reevaluated at age 15y.
  - At 15y, 9.4% to 11.0% had CVD risk clustering
  - 31.7% were overweight or obese
  - 20.0% had increased central adiposity.
- OR for CVD risk clustering at age 15:
  - 6.9 (95% CI:2.5, 19.0) if overweight/obesity at age 8
  - 3.6 (95% CI:1.0, 12.9) if increased waist circumference at age 8, but not independent of BMI
- BMI was the best long-term predictor of CVD risk

Children are not little adults

Need consistent supporting evidence that visceral adipose tissue or waist circumference measurements offer significant improvement over BMI in identifying cardiometabolic complications of obesity in children

Sagittal abdominal diameter (SAD)

- SAD distribution among adults in NHANES (Kahn et al. PLoS One 2014).
- SAD was associated with dysglycemia (HbA1c concentration >5.7%) independent of age, and of waist circumference or BMI
- Not widely used in children

NHANES Anthropometry Procedures Manual Jan 2011, p 3-24

Sagittal abdominal diameter in children

- Weber et al. *Diabetes Research and Clinical Practice* 2014.
- 65 adolescents, ages 11-17y, referred for assessment of cardiometabolic risk.

Table 2 – AUC for measures of abdominal adiposity and BMI to identify metabolic syndrome in males and females.

	AUC			AUC	
	Males	Females		Males	Females
BMI-Z	0.456	0.657	BMI	0.590	0.593
SAD	0.605	0.648	SAD	0.605	0.648
WC	0.561	0.778[a]	WC	0.561	0.778
WHR	0.614	0.833	WHR	0.614	0.833
BMI-Z + SAD	0.728	0.639	BMI + SAD	0.772	0.639
BMI-Z + WC	0.623	0.833[b]	BMI + WC	0.614	0.889
BMI-Z + WHR	0.597	0.852	BMI + WHR	0.614	0.843

[a] Statistically significant difference from BMI-Z, $p = 0.03$.
[b] Statistically significant difference from BMI-Z, $p = 0.02$.

SAD not superior to BMI, waist circumference or waist-to-hip ratio for detection of metabolic syndrome

Assessing excess adiposity

- Other anthropometric measures
  - Skinfold thickness
    - Requires skinfold calipers and training
    - Measures subcutaneous fat
    - Measurements on the limbs or trunk provides information about regional fat distribution

Triceps and Subscapular Skinfold Thickness Measurement

Skinfolds vs. BMI Correlations

(n=6866)		Skinfold Thickness		
	BMI	SF sum	Triceps	Subcapular
Triglycerides	0.33	0.33	0.30*	0.34
LDL cholesterol	0.19	0.19	0.17*	0.19
HDL Cholesterol	-0.21	-0.20*	-0.16*	-0.19*
Fasting insulin	0.46	0.43*	0.39*	0.43*
SBP	0.28	0.24*	0.22*	0.23*
DBP	0.19	0.18	0.18*	0.18*
Risk Factor Summary	0.50	0.47*	0.44*	0.47*

- Freedman et al. Am J Clin Nutr 2009, Bogalusa Study: Skinfold thickness measures are not more strongly correlated than BMI with cardiometabolic risk factors.

Anthropometry with Skinfolds

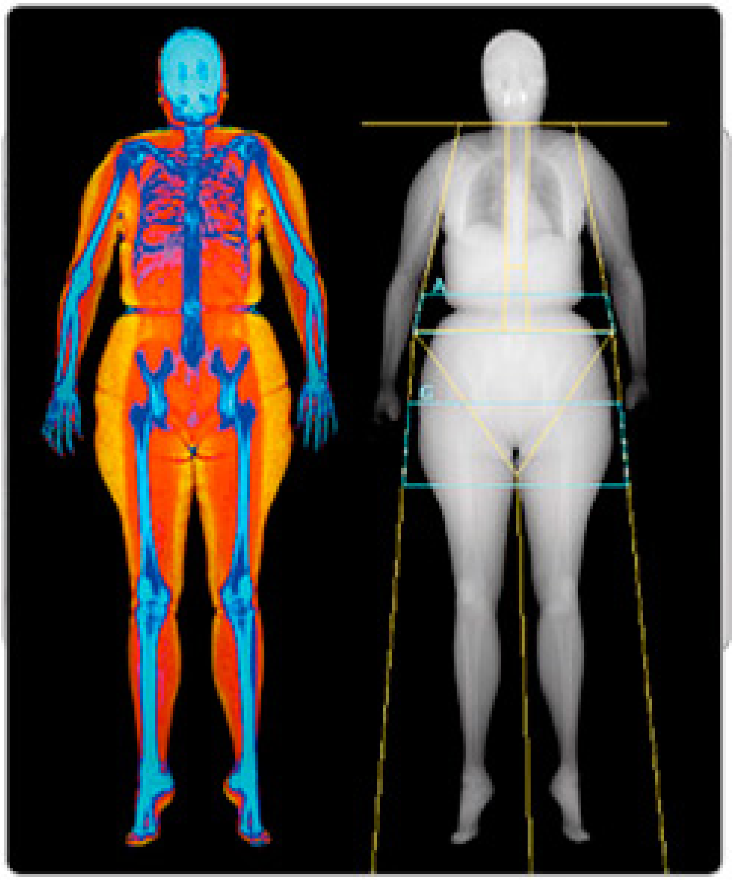
- Advantages
  - Relatively inexpensive
  - Portable (clinic and field settings)
  - Direct quantification of subcutaneous fat
  - Can characterize fat distribution
- Limitations
  - Requires skill and training
  - Modesty issues
  - Can’t measure subcutaneous fat in extremely overweight individuals
  - Not better than BMI at estimating body fat at high BMI levels or CMR risk

Other body composition techniques

- Bioelectrical impedance analyzers

- Air displacement plethysmography (Bod Pod)

Dual Energy X-ray Absorptiometry



http://www.itnonline.com/sites/default/files/imagecache/node_image/photo_article/BodyMan250x503.jpg

Whole Body Fan Beam Analysis

Image not for diagnostic use

TBAR2620

F.S. 68.00% -10.00%

Head assumes 17.0% brain fat

LBM 73.2% water

Region	Fat (g)	Lean+BMC (g)	Total (g)	%Fat (%)
L Arm	1205.0	3685.3	4890.3	24.6
R Arm	1203.9	3902.3	5106.2	23.6
Trunk	8246.8	31777.5	40024.2	20.6
L Leg	3683.0	11385.1	15068.1	24.4
R Leg	3794.4	11755.3	15549.8	24.4
Sub Tot	18133.0	62505.5	80638.6	22.5
Head	1087.4	4189.0	5276.4	20.6
TOTAL	19220.4	66694.5	85915.0	22.4

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DXA Percent Body Fat Reference Ranges for children

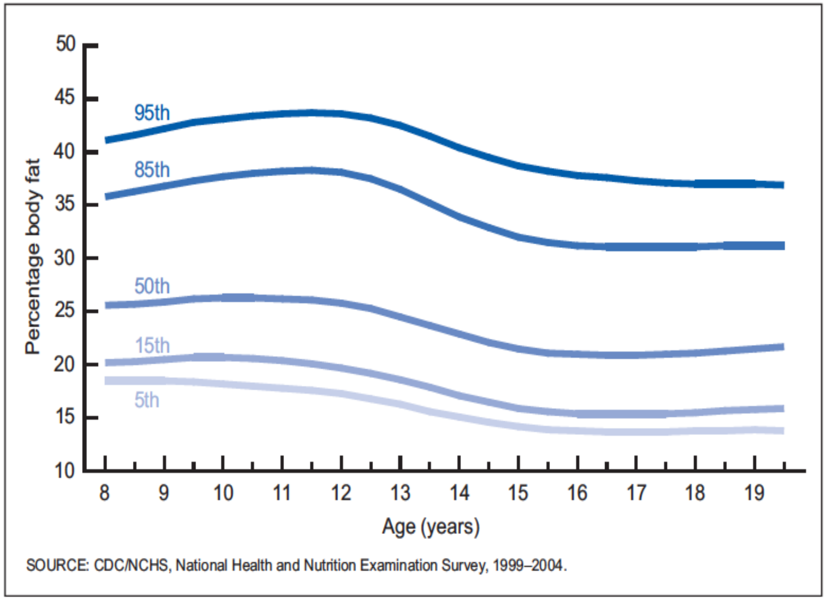


Figure 2. Selected percentiles of smoothed percentage body fat among boys aged 8–19 years: United States, 1999–2004

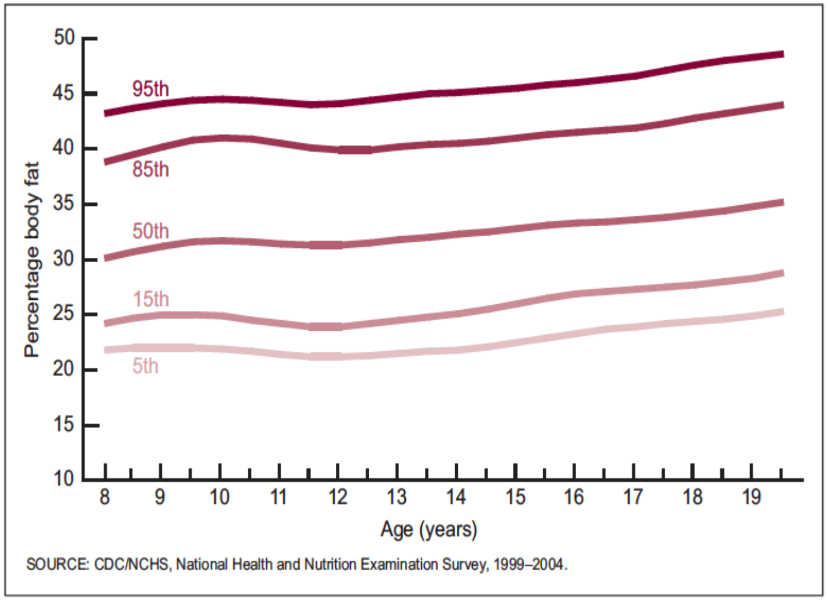
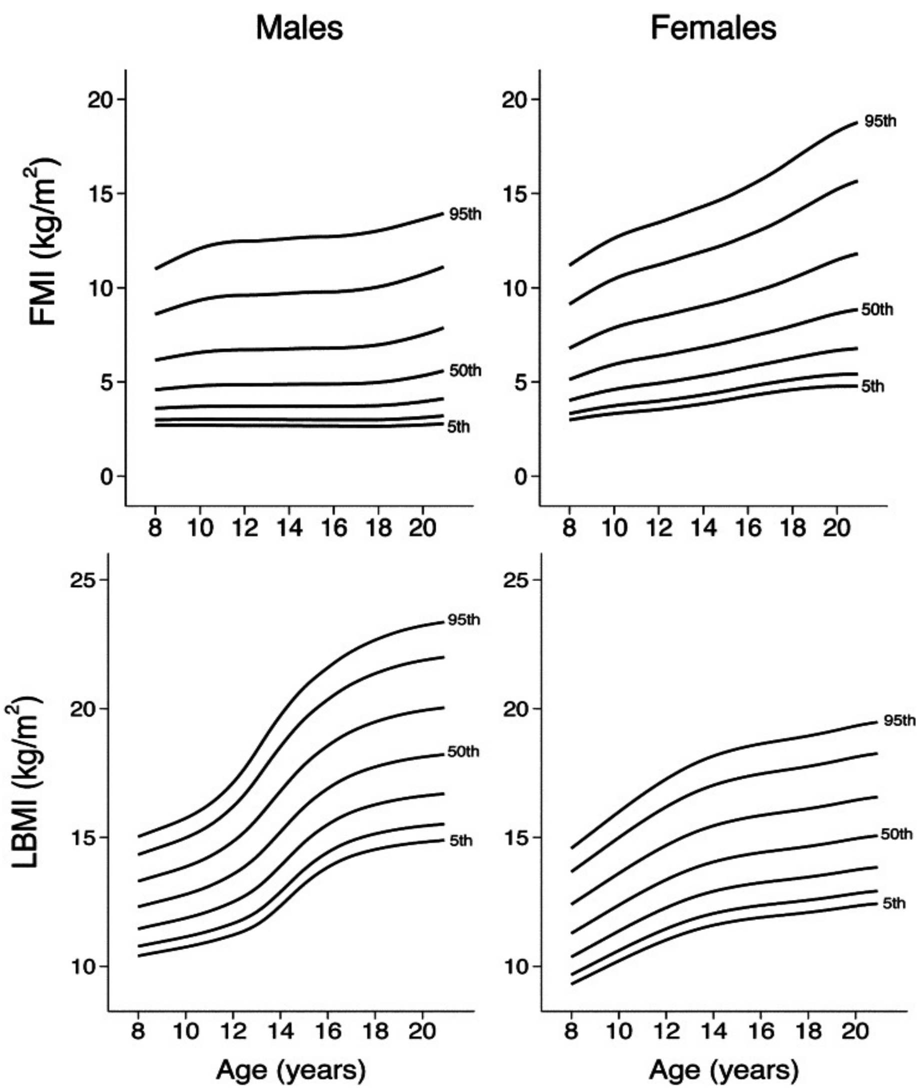


Figure 3. Selected percentiles of smoothed percentage body fat among girls aged 8–19 years: United States, 1999–2004

Ogden et al. National Health Statistics Report 43(9), 2011

DXA fat mass & lean mass index reference ranges for U.S. children



- Age and sex patterns
- Total body fat mass index [fat mass (kg)/height(m)^2]
- Lean body mass index [lean body mass (kg)/height(m) ^{2}]
- From Weber et al. Am J Clin Nutr. 2013 Jul; 98(1): 49–56.

Comparison of FMI and BMI to identify Metabolic Syndrome

- NHANES 1999–2006 data on 3004 participants, aged 12–20y with DXA and biomarkers of metabolic syndrome.
- FMI and LBMI were similar but not better than BMI in identifying metabolic syndrome

	AUC from unadjusted models	AUC for adjusted models
BMI-Z	0.867 (0.846, 0.887)	0.890 (0.866, 0.910)
FMI-Z	0.868 (0.847, 0.885)	0.887 (0.863, 0.905)
LBMI-Z	0.823 (0.797, 0.848)	0.857 (0.833, 0.879)
FMI-Z + LBMI-Z	0.869 (0.848, 0.889)	0.890 (0.867, 0.910)

Summary

- BMI is the simplest method to identify excess adiposity
- Waist circumference or waist to height ratio may provide additional information about metabolic risk, but results are not fully consistent
- Standardized procedures for measuring waist circumference are needed

Summary

- Advanced body composition techniques are not consistently better than BMI in identifying cardiometabolic risk
- "Children are not little adults"
  - Measures such as sagittal abdominal diameter and visceral adipose tissue don't show the same association in children as they do in adults
  - Developmental changes from birth to adulthood rarely considered and may be important