BMI: How does it measure up?

Babette S. Zemel, PhD
Director, Nutrition and Growth Laboratory
The Children’s Hospital of Philadelphia
University of Pennsylvania Perelman School of Medicine
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

- Pseudotumor cerebri
- Dyslipidemia
- Hypertension
- Chronic inflammation
- Enothelial dysfunction
- Type 2 diabetes
- Precocious puberty
- Polycystic ovary syndrome (girls)
- Hypogonadism (boys)
- Slipped capital femoral epiphyses
- Blount's disease
- Forearm fracture
- Flat feet
- Poor self esteem
- Depression
- Eating Disorders
- Sleep apnea
- Asthma
- Exercise intolerance
- Gallstones
- Steatohepatitis
- Glomerulosclerosis

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- Poor self esteem
- Depression
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Neurological
- Pseudotumor cerebri

Pulmonary
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Cardiovascular

Gastrointestinal

Renal

Musculoskeletal

Endocrine

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- **Psychosocial**
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  - Slipped capital femoral epiphyses
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- **Endocrine**
  - Type 2 diabetes
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- **Eating Disorders**

- **Sleep apnea**

- **Asthma**

- **Exercise intolerance**

- **Gallstones**

- **Steatohepatitis**

- **Glomerulosclerosis**

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>TC≥200</th>
<th>HDL-C &lt;40mg/dL</th>
<th>Non-HDL-C ≥145 mg/dL</th>
<th>Dyslipidemia</th>
<th>Borderline Hi or High BP</th>
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</thead>
<tbody>
<tr>
<td>Total</td>
<td>7.8</td>
<td>12.8</td>
<td>8.4</td>
<td>20.2</td>
<td>11</td>
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<tr>
<td>Normal</td>
<td>7.7</td>
<td>6.7</td>
<td>7.2</td>
<td>14.6</td>
<td>8.4</td>
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<tr>
<td>Overweight</td>
<td>5.8</td>
<td>12.5</td>
<td>8</td>
<td>18.2</td>
<td>12.8</td>
</tr>
<tr>
<td>Obese</td>
<td>9.8</td>
<td>31.5</td>
<td>13.7</td>
<td>39.3</td>
<td>18</td>
</tr>
</tbody>
</table>

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?

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

Visceral vs subcutaneous fat

- 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 correlates well with cross-sectional measures of total fat, subcutaneous fat and visceral fat in 145 children, ages 8 to 17y

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

http://www.statcan.gc.ca/pub/82-003-x/2012003/article/11707/c-g/fig1-eng.gif

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
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

<table>
<thead>
<tr>
<th>Model number</th>
<th>Independent Variable</th>
<th>Beta</th>
<th>SE</th>
<th>p</th>
<th>R²</th>
<th>Model number</th>
<th>Beta</th>
<th>SE</th>
<th>p</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>-0.023</td>
<td>0.018</td>
<td>0.207</td>
<td></td>
<td>1</td>
<td>Age</td>
<td>-0.023</td>
<td>0.018</td>
<td>0.207</td>
</tr>
<tr>
<td></td>
<td>Gender</td>
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<td>0.051</td>
<td>0.640</td>
<td></td>
<td>Gender</td>
<td>-0.024</td>
<td>0.051</td>
<td>0.640</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Race</td>
<td>0.118</td>
<td>0.051</td>
<td>0.022</td>
<td></td>
<td>Race</td>
<td>0.118</td>
<td>0.051</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pubertal Status</td>
<td>-0.258</td>
<td>0.085</td>
<td>0.003</td>
<td>0.22</td>
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<td>-0.258</td>
<td>0.085</td>
<td>0.003</td>
<td>0.22</td>
</tr>
<tr>
<td>2</td>
<td>BMI percentile</td>
<td>-0.251</td>
<td>0.065</td>
<td>&lt;.001</td>
<td>0.30</td>
<td>2</td>
<td>WC</td>
<td>-2.413</td>
<td>0.249</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>3</td>
<td>BMI percentile</td>
<td>0.118</td>
<td>0.067</td>
<td>0.080</td>
<td></td>
<td>3</td>
<td>WC and</td>
<td>-2.772</td>
<td>0.320</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>and WC</td>
<td>-2.772</td>
<td>0.320</td>
<td>&lt;.001</td>
<td>0.56</td>
<td>BMI Percentile</td>
<td>0.118</td>
<td>0.067</td>
<td>0.080</td>
<td>0.56</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Independent Variable (Top tertile vs. rest)*</th>
<th>OR</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Arterial Pressure (mm Hg)</td>
<td>1.30</td>
<td>0.92-1.83</td>
<td>0.13</td>
</tr>
<tr>
<td>LDL Cholesterol (mg/dl)</td>
<td>1.66</td>
<td>1.18-2.32</td>
<td>0.003</td>
</tr>
<tr>
<td>Triglycerides (mg/dl)</td>
<td>1.47</td>
<td>1.02-2.11</td>
<td>0.03</td>
</tr>
<tr>
<td>HDL Cholesterol (mg/dl)</td>
<td>2.01</td>
<td>1.44-2.79</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Glucose (mg/dl)</td>
<td>1.13</td>
<td>0.77-1.66</td>
<td>0.51</td>
</tr>
<tr>
<td>Insulin (µU/ml)</td>
<td>2.05</td>
<td>1.16-3.62</td>
<td>0.01</td>
</tr>
<tr>
<td>Insulin Resistance Index (HOMA-IR)</td>
<td>1.43</td>
<td>0.78-2.62</td>
<td>0.23</td>
</tr>
</tbody>
</table>

*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

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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

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

*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.

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

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
Waist vs BMI as long term predictors of risk


- 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


999 individuals, ages 6 to 90 y, from 111 families in Midwest U.S. studies

In children and adolescents:

 Subcutaneous adiposity (MRI) was the best predictor of insulin resistance (HOMA) and triglycerides
 BMI percentile was the best predictor for HDL-c and LDL-c

In adults:

 Waist-height ratio, visceral/subcutaneous fat ratio and BMI were the most significant predictors of insulin resistance
 Visceral fat and BMI best predicted triglycerides
 Visceral fat best predicted LDL-c

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 was associated with dysglycemia (HbA1c concentration >5.7%) independent of age, and of waist circumference or BMI.
- Not widely used in children.
Sagittal abdominal diameter in children

- 65 adolescents, ages 11-17y, referred for assessment of cardiometabolic risk.

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

<table>
<thead>
<tr>
<th>(n=6866)</th>
<th>BMI</th>
<th>SF sum</th>
<th>Triceps</th>
<th>Subcapular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triglycerides</td>
<td>0.33</td>
<td>0.33</td>
<td>0.30*</td>
<td>0.34</td>
</tr>
<tr>
<td>LDL cholesterol</td>
<td>0.19</td>
<td>0.19</td>
<td>0.17*</td>
<td>0.19</td>
</tr>
<tr>
<td>HDL Cholesterol</td>
<td>-0.21</td>
<td>-0.20*</td>
<td>-0.16*</td>
<td>-0.19*</td>
</tr>
<tr>
<td>Fasting insulin</td>
<td>0.46</td>
<td>0.43*</td>
<td>0.39*</td>
<td>0.43*</td>
</tr>
<tr>
<td>SBP</td>
<td>0.28</td>
<td>0.24*</td>
<td>0.22*</td>
<td>0.23*</td>
</tr>
<tr>
<td>DBP</td>
<td>0.19</td>
<td>0.18</td>
<td>0.18*</td>
<td>0.18*</td>
</tr>
<tr>
<td>Risk Factor Summary</td>
<td>0.50</td>
<td>0.47*</td>
<td>0.44*</td>
<td>0.47*</td>
</tr>
</tbody>
</table>

- 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

![Dual Energy X-ray Absorptiometry Image](http://www.itnonline.com/sites/default/files/imagecache/node_image/photo_article/BodyMan250x503.jpg)

### Whole Body Fan Beam Analysis

*Image not for diagnostic use*

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

**Delphi A**

*SN: 45775*  
*Version 11.2 :3 01/29/2003 09:33*
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 \([\text{fat mass (kg)/height(m)}^2]\)
- Lean body mass index \([\text{lean body mass (kg)/height(m)}^2]\)
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

<table>
<thead>
<tr>
<th></th>
<th>AUC from unadjusted models</th>
<th>AUC for adjusted models</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI-Z</td>
<td>0.867 (0.846, 0.887)</td>
<td>0.890 (0.866, 0.910)</td>
</tr>
<tr>
<td>FMI-Z</td>
<td>0.868 (0.847, 0.885)</td>
<td>0.887 (0.863, 0.905)</td>
</tr>
<tr>
<td>LBMI-Z</td>
<td>0.823 (0.797, 0.848)</td>
<td>0.857 (0.833, 0.879)</td>
</tr>
<tr>
<td>FMI-Z + LBMI-Z</td>
<td>0.869 (0.848, 0.889)</td>
<td>0.890 (0.867, 0.910)</td>
</tr>
</tbody>
</table>
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