Body Composition

- Percent of body weight that is body fat
- Two classifications of body fat
  - Essential - necessary for optimal health
    - Fat in bone marrow
    - Cell membranes
  - Nonessential or storage
    - Subcutaneous adipose tissue
    - Visceral fat

Essential Fat

- Males – 2-3%
- Females – 5-12% (varies)

Percent Body Fat Standards

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>At risk+</td>
<td>≤ 5%</td>
<td>≤ 8%</td>
</tr>
<tr>
<td>Below average</td>
<td>6-14%</td>
<td>9-22%</td>
</tr>
<tr>
<td>Average</td>
<td>15%</td>
<td>23%</td>
</tr>
<tr>
<td>Above average (ow)</td>
<td>16-24%</td>
<td>24-31%</td>
</tr>
<tr>
<td>At risk* (obesity)</td>
<td>≥25%</td>
<td>≥32%</td>
</tr>
</tbody>
</table>

+ diseases/disorders associated with malnutrition
* Diseases associated with obesity

Hydrostatic Weighing

- Two compartment model
  - Fat mass (FM) – all extractable lipids
  - Fat free mass (FFM) - water, muscle, bone, connective tissue, and organs

Fat Free Mass vs Lean Body Mass

- Lean body mass = FFM + essential fat
Hydrostatic Weighing

- Calculate body density
  - Density = mass/volume
  - Mass – weigh on land
  - Volume – Archimedes Principle of Displacement

Archimedes Principle of Displacement

- A partially or fully submerged object experiences an upward buoyant force equal to the weight or the volume of the fluid displaced by the object
- Loss of weight under water is directly proportional to the body volume

Density

- g/cm³
- Fat = 0.901 g/cm³
- FFM = 1.10 g/cm³
- Range of body density in population
  - 0.93 – 1.10 g/cm³

Body Density

\[
\text{Density of water} = \frac{\text{Weight in air} - \text{Weight in water}}{\text{Volume of displaced water}}
\]

1 L of displaced water has a buoyant force exerted that is equivalent to 1 kg at 4 degrees C

Potential Sources of Error

- Assumption of density of FFM is not same for all individuals
  - FFM is not constant – varies with growth, maturation, age, gender and ethnicity (± 2% variation in FFM within a homogenous group)
- Residual volume should be measured – estimation can produce errors of 2.8 – 3.7% in % body fat
- Subject cooperation – anxiety, clothing, and cooperation
- Air in intestines

Factors Affecting FFM

- Bone density
- Body water
- Age
- Race
- Gender

A note – load cell vs autopsy scale
Examples of Variations

- African Americans – higher bone density
  - FFM women = 1.106 g/cm³
  - FFM men = 1.113 g/cm³
  - Underestimate % body fat with 2 compartment models
- Children and elderly - lower bone density
  - Children FFM = 1.084 g/cm³
  - Elderly FFM = 1.096 g/cm³
  - Overestimate % body fat with 2 compartment model

Anthropometry

- Study and technique of human body measurement, includes height, weight, girth, bone diameters and skinfold measurements

Height/weight Charts

- Metropolitan Life Insurance Co. Charts
- 1959 Blood and Blood Pressure Build Study
- 26 life insurance companies
- 5 million insured people for up to 20 years
  - Purchased nongroup insurance (25-59 years of age)
  - Heart disease, cancer or diabetes excluded
  - Smokers included
  - Self-reported weights (some)
- Shoes and indoor clothing
- Method for determining frame size not given
- Desirable weights based on lowest mortality

- 1973 – recalculated to express heights without shoes and weights without clothes
  - Fogarty Intl Center Conference on Obesity
- 1983 – Metropolitan Life Ins Co issued new ht/wt charts
  - Frame size based on NHANES
  - Weight ranges 2-3% higher than 1959 tables
  - Tables based on specific populations
  - No consideration for smoking (skewed ideal weights upward)
  - Not based on lowest mortality
  - Initial data collection only
  - Muscle differences
- *1959 better except for elderly

Example

- Male
  - Height - 70 in. (stadiometer)
  - Weight - 180 pounds
  - Elbow breadth 2.75 in.
Example

- Select frame size
  - Medium
- Select midpoint of recommended weight range
  - 151 - 163 pounds
  - 157 pounds
- Body wt/recommended wt = % + weight
  - 180/157 = 1.14 = 114% of ideal body weight
- 14% above ideal weight

Standards for Relative Weight

<table>
<thead>
<tr>
<th>Range</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 90%</td>
<td>underweight</td>
</tr>
<tr>
<td>90-110%</td>
<td>desirable</td>
</tr>
<tr>
<td>111-119%</td>
<td>overweight</td>
</tr>
<tr>
<td>120-139%</td>
<td>mild obesity</td>
</tr>
<tr>
<td>140-199%</td>
<td>moderate obesity</td>
</tr>
<tr>
<td>≥ 200%</td>
<td>severe obesity</td>
</tr>
</tbody>
</table>

Body Mass Index

- Used in large population studies
- Measure of obesity
- Index of weight relative to height
  - Quetelet index (kg/m²)
- Overweight – 25.0 – 25.9 kg/m²
  - obesity-related health problems increase beyond a BMI of 25 kg/m²
- Obesity - ≥ 30 kg/m²

Body Mass Index

- r = 0.70 compared to hydrostatic weighing
- Low cost
- Easy to measure
- Difficult to interpret to patients – wt loss
- Not useful in athletic, muscled individuals
- Not a sensitive indicator of changes in body composition
  - Increase FFM = increase in wt = increase BMI

Estimating Ideal Body Wt Based on Height - Dietitians

Women: 100# for 5 ft + 5# for each in. above 5 ft

Men: 106 # for 5 ft + 6# for each in. above 5 ft

Waist/Hip Ratio

- Regional fat distribution
- Type of obesity
  - Android obesity (upper body obesity) – apple
  - Gynoid obesity (lower body obesity) – pear
- Males vs Females
- Menopause
- Pattern of fat distribution – good predictor of health risks of obesity
Waist/Hip Ratio

- HTN, NIDDM, Hyperlipidemia, CAD and premature death compared to individuals with equal fat but lower ratios
- Not give idea of ideal body weight
- Good tool for assessing disease risk
- Easy to measure
- Low cost

Increased Risk of Disease

< 60 yrs
- Males > 0.95
- Females > 0.82

60-69 yrs
- Males > 1.03
- Females > 0.90

Focus shifting to waist circumference alone or waist circumference and BMI

Diameters

- Used as indices of body frame
- Somatotyping
  - Endomorph – round, soft
  - Mesomorph – muscular
  - Ectomorph – lean, fragile, linearity
- Alone – no relationship between skeletal size and amount of body fat
- Can be utilized in conjunction with other measures

Circumferences

- Error in predicting body fat - 2.5-4.0%
- Requires little equipment
- Useful in obese – skinfolds a problem
- Assume as increase circumference, increase body fat
- Not useful for predicting body fat in very thin, very fat or athletic
- Not good to assess changes in fat free mass over time
- Low cost
- Little skill

Skinfold Measurements

- Most accurate predictor of body density compared to other anthropometric measures correlated to hydrostatic weighing
- Constant pressure of 10 g/mm²
- Cost $300-500
- Fast enough for mass testing
- Little space required
**Skinfold Measurements**

- Skill required
- Ideal – same technician for retests (intertester reliability)
- Not after exercise/sweating
- Accuracy ± 3-5%

**Assumption**
- Total subcutaneous adipose tissue mass is represented by the selected skinfold sites
- Subcutaneous tissue has a known relationship with total body fat
  - 1/3 total fat (varies)
  - Increasing age – less fat stored subcutaneously
  - Important to use equations that...
    - Age-adjusted
    - Population-specific for athletic groups

**Error**

- Largest source – improper location of site
- Practice – 50-100 people for skill
- Same technician for pre and post

**Why use sum of skinfolds rather than individual values?**

---

**Table 2. Intertester error in selected skinfold sites using experienced investigators (45).**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Suprailiac</th>
<th>Abdomen</th>
<th>Triceps</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Practice</td>
<td>5.6 mm</td>
<td>2.7 mm</td>
<td>1.7 mm</td>
<td>2.9%**</td>
</tr>
<tr>
<td>Practice*</td>
<td>1.8 mm</td>
<td>0.9 mm</td>
<td>1.0 mm</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

*Denotes 30-minute practice session to review exact site selection.
**Percent fat was estimated from all three skinfold measures.

---

**Table 3. Intertester error for testers of varied experience but who practiced together (26).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tester 1*</th>
<th>Tester 2</th>
<th>Tester 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>F-ratio</td>
</tr>
<tr>
<td>Skinfolds (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>18.0</td>
<td>19.4</td>
<td>17.2</td>
</tr>
<tr>
<td>Axilla</td>
<td>16.9</td>
<td>17.9</td>
<td>16.1</td>
</tr>
<tr>
<td>Triceps</td>
<td>15.9</td>
<td>16.7</td>
<td>15.8</td>
</tr>
<tr>
<td>Suprailiac</td>
<td>19.8</td>
<td>21.4</td>
<td>22.8</td>
</tr>
<tr>
<td>Abdomen</td>
<td>31.3</td>
<td>30.9</td>
<td>32.2</td>
</tr>
<tr>
<td>Suprailiac</td>
<td>39.9</td>
<td>30.6</td>
<td>19.1</td>
</tr>
<tr>
<td>Thigh</td>
<td>21.6</td>
<td>20.9</td>
<td>19.1</td>
</tr>
<tr>
<td>Sum of Seven</td>
<td>144.9</td>
<td>146.7</td>
<td>148.3</td>
</tr>
<tr>
<td>Sum of Three</td>
<td>70.9</td>
<td>71.1</td>
<td>72.6</td>
</tr>
<tr>
<td>Percent Fat Estimates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>= 7</td>
<td>32.0</td>
<td>32.0</td>
<td>20.3</td>
</tr>
<tr>
<td>= 3</td>
<td>18.3</td>
<td>19.4</td>
<td>19.5</td>
</tr>
</tbody>
</table>

*Tester 1 was most experienced and tester 3 was least experienced.
Body Composition Prediction Equations

- Population-specific – small homogenous sample with limited application
  - Assume a linear relationship between skinfolds and body density - large prediction errors at extremes
  - Overestimate body fat in lean
  - Underestimate body fat in fatter subjects

- Generalized – large heterogeneous samples which vary greatly in body fatness
  - Assumes a quadratic relationship between skinfolds and body density - no loss of prediction accuracy at extremes
  - One equation replaces several without loss of accuracy
  - Valid for adults varying greatly in age and body

Body Composition Prediction Equations

Selecting an equation

- Sum of 7 skinfolds – highest correlation with hydro
- Sum of 3 can also be used with minimal loss of accuracy – feasibility
- Recommendation –
  - Sum of 3 men – chest, abdomen, thigh
  - Sum of 3 women – triceps, suprailium, and thigh
- Consider removal of clothing
Statistical Techniques

• Multiple regression – identify an equation that used the best combination of measured variables for predicting body composition sum of SF and age
• Good prediction equation yields a high multiple correlation coefficient
• Standard Error of Estimate (SEE) – individual’s predicted score relative to the individual’s reference
• Regression line – line of best fit – scatter plot

Consideration in Choosing a Method

1. Reliability – extent to which a test yields the same results on successive trials
   - Intertester – difference between individuals – t-test
     • Where site is located
     • Most variability in abdomen and thigh, least in tricep and subscapular
     • Clothes

Considerations

• Reliability
  - Intratester reliability – successive trials by same technician on same subject
    • Experts – 0.85 – 0.90 (50-100 subjects)
    • 2-5 trials
  2. Validity – ability to assess the variable to be measured
    - A. Validity coefficient $\geq 0.80$ $R_{mc}$
      • 64% of variation in reference measure accounted for by predictors in equation

• Validity – t-test
  B. $>$0.05 (not significantly from the reference value)
    - Must have both A and B under validity

3. What is the reference method?
   - hydro or DEXA

4. Sample size used to develop prediction equation
   - 10-20 subjects/predictor variable
   - Larger N produces more stable regression weights for the predictor variables
Considerations

5. SEE - degree of deviation of the individual points about the line of regression ± 3.5%
6. To whom is the equation applicable?
7. How were the variables measured by the researchers?
8. Was it cross-validated?

Bod Pod

- Air displacement plethysmography
- Measures variations in volume via air displacement
- Two-component model
- 3-5 minutes
- Special populations - obese, elderly, and disabled

Bod Pod

- Mobile
- Minimal training
- Reliable (r>0.90)
- Valid ± 0.3 % of hydrostatic weighing (r = 0.96)
- Needs further validation on athletes, children, homogenous groups with average levels of body fat

Bioelectrical Impedance Analysis

- A small electrical current is passed through the body
- Actually measures total body water (TBW)
- Measure impedance (resistance to flow)
- FFM - good conductor, low impedance
- FM - poor conductor, high impedance
- Requires little technician skill
- Follow strict procedures
Procedures for BIA
• Abstain from eating or drinking within 4 hours of assessment
• Avoid moderate or vigorous exercise within 12 hours of assessment
• No alcohol within 48 hours
• No diuretic agents – caffeine, etc. unless prescribed by physician
• Urinate within 30 minutes
• Not test during menstrual cycle if retaining water
• Consistent ambient temperature

BIA
• Accuracy depends on normal hydration
  - Hydration effect controversial – probably depends on whether the electrolyte compartment changes proportionally to water
• Accuracy depends on regression equation
  - must be population specific
• Equation must be specific to equipment – arm to leg, leg to leg, and arm to arm
• Less research on scales and hand-held devices than electrodes
• If correct equation, accuracy shown to equal skinfolds

Dual Energy X-ray Absorptiometry
• 3 compartment model- fat, bone and lean soft tissue
• Measures differences in absorption of 2 different low X-ray energies
• Small dose of radiation
• Expensive - > $30,000
• ~ 10-20 minutes
• Little subject cooperation required
• Error is <2% compared to densitometry

Near-Infrared Interactance
• Based on light absorption and reflection
• Developed by USDA to assess body composition of livestock
• Futurex-5000 - portable
• Uses probe that emits two frequencies of low-energy beam near-infrared light over biceps
• Body fat absorbs the light and FM reflects the light
• Detector in probe measures intensity of the reflected light (OD)
• Accuracy is questionable
• Uses bicep image only - no disrobing
NIR

- Must clean wand after each test
- Change activity level, changes % body fat
- Little training required
- Not affected by menstrual cycle
- Unacceptable prediction errors (3.7-6.3%)
- More research needed – not accurately predict body fat across across a broad range of body fat levels
- Overestimates body fat in lean and underestimates in fatter
- Not accurately assess body composition changes from resistance training