Human Body Composition and Energy Expenditure

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PUH 690 “Energetics: Scientific Foundations of Obesity and Other Health Aspects”
Overview

I. Body composition (fat, lean, bone)

II. Fat distribution
   - Subcutaneous adipose tissue
   - Visceral adipose tissue
   - Ectopic fat (liver, muscle)
   - Brown adipose tissue

III. Energy Expenditure
Part I: Body composition

- Dual-energy X-ray absorptiometry (DXA)
- Air-displacement plethysmography
  - BodPod
  - PeaPod
- Stable isotope dilution
Dual-energy X-ray absorptiometry

- Differential attenuation of two X-ray beams of differing strength
- Bone > lean mass > fat mass
- “R” values = X-ray attenuation
- Extrapolated R value when bone obscures soft tissue
DXA

Total & regional fat mass, lean mass, bone mineral content and density
DXA analysis image
# University Of Alabama At Birmingham

1675 University Blvd.  
Birmingham, AL 35294

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## BODY COMPOSITION

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<th>Region (%Fat)</th>
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<th>Lean (g)</th>
<th>BMC (g)</th>
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## FAT MASS RATIOS

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<th>Trunk/Total</th>
<th>Legs/Total</th>
<th>(Arms+Legs)/Trunk</th>
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Body density with Bod Pod

- Body volume by air displacement
- Body density by volume and mass
- Body volume corrected for tidal volume
Air-displacement plethysmography
Body density via “Bod Pod”
Bod Pod
Bod Pod
Body density with Bod Pod

- > mass/volume = > density
- > density = > lean:fat
- \( \% \text{fat} = \left(\frac{4.95}{D_b} - 4.5\right) \times 100 \) (Siri, 1956)
Pea Pod for infant body composition
Stable Isotope Dilution
Total body water via deuterium ingestion
TBW with deuterium dilution

- Baseline urine sample
- Oral dose of $\text{D}_2\text{O}$
- Deuterium: $1 \text{ P} + 1 \text{ N}$ (H has 1 P)
- 3-4 hour equilibration period
- Second urine sample
- Deuterium enrichment (delta) by IRMS

$$\text{TBW} = \frac{(\text{dose} \times C_1 \times C_2)}{\Delta T_{180} - \Delta T_0 / 1000}$$

$$36.13\text{kg} = 9.998\text{g} \times 5651619 \times 0.945 / 1482 - 3.9 / 1000$$
Multi-compartment modeling

- % Fat = (equation)
  - Total body water (isotope dilution)
  - Total body bone mineral content (DXA)
  - Body density (Bod Pod)
- Multiple direct measures
- Fewest assumptions
Fat mass (kg) = 2.05 * weight (kg) * ((1.34/D_b) – (0.35 * (TBW/weight)) + (0.71624 * (bone/weight)) – 1)
Part II: Fat Distribution

- Subcutaneous adipose tissue:
  - DXA (dual-energy X-ray absorptiometry)
  - CT (computed tomography)
  - MRI (magnetic resonance imaging)
- Visceral adipose tissue: CT, MRI
- BAT: PET (Positron Emission Tomography)
- Ectopic fat
  - Intramuscular fat: CT, MRI, MRS (spectroscopy)
  - Liver fat: CT, MRS, MRI
Regional body composition with DXA
Fat Distribution by CT scan
CT Scan Image
Computed tomography scanning

- Single slice X-ray; 5 mm, 2 sec
- Attenuation of beam in Houndsfield units
- Denser tissue = greater attenuation
- Bone > Lean mass > fat mass
Computed tomography scanning

- Adipose tissue = -190 to -30 HU
- Muscle = 0 – 80 HU
- Low-density muscle = 0 - 20 HU
  - Indicates lipid infiltration
- High-density muscle = 21-80 HU
Skeletal Muscle Fat

- Magnetic resonance spectroscopy (MRS)
  - $^1$H methylene proton resonance
  - Intramyocellular (IMCL)
  - Extramyocellular (EMCL)
- Magnetic resonance imaging (MRI)
  - Visualize fat depots
- Computed tomography (CT)
  - Attenuation value; lower density = more fat
- Biopsy
  - Oil red O staining; microscopy
Magnetic Resonance Spectroscopy for IMCL
MRS Measurement

- $^1$H-MRS of right soleus on a 4.1T magnet
- IMCL – 6x6 voxel average
- Extramocellular lipid (EMCL) – total soleus voxel average
- Normalized to an oil phantom
Water-suppressed 1H spectra collected with a 9.5 cm surface coil. EMCL=extramyocellular lipid; IMCL=intramyocellular lipid; Cr=creatine.
Magnetic Resonance Imaging: Intra-muscular adipose tissue “IMAT”

Mid-Thigh

Courtesy Amy Goss
MRI for abdominal fat

Courtesy Amy Goss
MRI for liver fat

Attenuation of 5 ROI is used as an index of liver fat

Courtesy Amy Goss
PET
PET scanning for BAT

Cold-induced BAT activity using $^{18}$F-fluorodeoxyglucose
Part III: Energy Expenditure

- Indirect calorimetry
  - Resting: Vmax ENCORE 29N Systems metabolic monitor (SensorMedics)
  - 24-h whole room
- Doubly-labelled water
  - Deuterium
  - Oxygen-18
Indirect calorimetry

- Oxygen consumption
- Carbon dioxide production
- 30-min canopy method
  - Resting energy expenditure
- 24-hour room method
  - Total (24-h), resting, and sleeping EE
  - Total includes PA and TEF
Resting Energy Expenditure
Indirect Calorimetry
## Sample report

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<th>V̇CO₂ L/min</th>
<th>RQ</th>
<th>VE(BTPS) L/min</th>
<th>FIO₂ %</th>
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</table>

Measured REE: 990 kcal/day
Respiratory Quotient: 0.87
Mean VO₂: 0.140 L/min
Mean VCO₂: 0.123 L/min
Calculation of energy expenditure

- REE = [VO2 (3.94) + VCO2 (1.11)] 1440 min/day
24-h Energy Expenditure
Room Calorimetry
Free-living Total & Activity-related Energy Expenditure
Deuterium, $^{18}$O labeled water
Doubly-Labeled Water

- Baseline urine collection
- Oral dose of $\text{D}_2\text{O}^{18}$
- Day 1 urine collection
- Day 14 urine collection
- Deuterium and $^{18}\text{O}$ enrichment by IRMS
Isotopic enrichment in urine

- O equilibrates between water and CO₂
- Oxygen eliminated as both water and CO₂
- Hydrogen eliminated only as water
  - Differential=CO₂ flux

Baseline enrichment

**Time (days)**

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<td>C¹⁸O₂</td>
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<td>(oxygen)</td>
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Calculation of energy expenditure

- TEE from standard indirect calorimetry equations
  - \[ r_{\text{CO}_2} = 0.4554 \left( k_0 \times V_0 - k_h \times V_h \right) \]
  - \[ \text{TEE (kcal/d)} = 3.9 \times r_{\text{CO}_2} / RQ + 1.11 \times r_{\text{CO}_2} \]
- AEE = \((0.9 \times \text{TEE}) - \text{REE (from indirect cal.)}\)

k and V reflect turnover rate and pool size; 
RQ = 0.85 or FQ 
Wolfe text ch. 12
Questions?