Accuracy of methods for measuring and predicting energy expenditure

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Measurement/ Estimation

Measurement:
- Whole body calorimetry

Estimation:
- Indirect calorimetry
- Doubly labeled water
- Sensewear Armband
- Equations
Whole body (direct) calorimetry
Whole body (direct) calorimetry

- Measurement of energy expenditure by direct measurement of the body’s heat production
- Sealed room sized chamber (calorimeter) to detect heat loss

The calorie is a unit of energy:
- 1 kcal is the energy needed to increase the temperature of 1g of water by 1°C
- (ie 4.2 joules)
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Whole body (direct) calorimetry

Advantages:
- Measurement accuracy of < 2%* (Blaza & Garrow, 1983)
  - *if measured over 24hr and no heat loss

Disadvantages:
- confinement affects energy expenditure
- operation/ design:
  - walls, floor, roof must be sensitive to heat
  - measurement must exclude anything (other than the subject) which emits heat
  - requires long study periods
Doubly labeled water technique
Doubly labeled water technique

- Non calorimetric method
- Developed in the 1980’s (Scholler & van Senten 1982)
- Provides info on the total energy expenditure of a free living individual for periods of up to 3wks
Subject takes oral dose of stable isotopes
- $^2$H (dueterium) and $^{18}$O
- Isotopes mix with normal hydrogen and oxygen in the body
- As energy is expended CO$_2$ and H$_2$O are produced
- CO$_2$ is lost in the breath, H$_2$O is lost in the breath, urine and via skin
- Difference between the 2 is used to calculate CO$_2$ production
- CO$_2$ is used to calculate energy expenditure
- Rates of loss measured in the urine
Doubly labeled water technique

Advantages:
- Provides data on total energy expenditure of free living individuals

Disadvantages
- No differentiation between REE and activity
- Limited to healthy individuals
Indirect calorimetry
Indirect calorimetry

- Indirect calorimetry measures gas \((O_2 \& CO_2)\) exchange as a measure of heat production.
- Estimation of heat production based on Hess’s law:
  - \(O_2\) is consumed, \(CO_2\) produced and \(N\) excreted in proportion to the heat generated.
Indirect calorimetry:

- divided into two types:
  - closed circuit
  - open circuit
Indirect calorimetry: closed circuit method

closed circuit methods:
- $\text{CO}_2$ produced is absorbed within the system
- $\text{O}_2$ is added to maintain the volume of the gas constant
- $\text{O}_2$ consumption measured from the reduction in the volume of the gas by using a spirometer

disadvantages:
- absorption of $\text{CO}_2$ mean the value of RQ cannot be calculated
- a value of 0.82–0.85 was assumed
- error of up to $\pm 6\%$ (Henry 2005)
- in mechanically ventilated patients the closed-circuit technique is extremely vulnerable to error
**Indirect calorimetry:**
**respiratory quotient (RQ)**

- RQ is the ratio of moles of CO\(_2\) produced to moles of O\(_2\) consumed for a given amount of nutrient
- Close to 0.7 for fat and 1.0 for CHO

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>RQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>0.994</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.995</td>
</tr>
<tr>
<td>Fat</td>
<td>0.710</td>
</tr>
<tr>
<td>Protein</td>
<td>0.806</td>
</tr>
<tr>
<td>Alcohol</td>
<td>0.663</td>
</tr>
</tbody>
</table>
Indirect calorimetry: open circuit method

- several different models available using a variety of gas sampling techniques:
  - mixing-chamber technique e.g. deltatrac
  - breath-by-breath technique e.g. M-COVX
Indirect calorimetry: mixing chamber technique

- most common is the Deltatrac
- measures REE by continuous measurements of \( \text{VO}_2 \) and \( \text{VCO}_2 \)
- has a paramagnetic \( \text{O}_2 \) and an infrared \( \text{CO}_2 \) sensor
  - allows for continuous and accurate measurements of gas concentration differences between inspired and expired air
  - avoids interference of the flow sensors by using an air dilution technique whereby the expiratory gases are diluted in a known, constant flow
  - expired gases travel to the mixing chamber where they are sampled
  - provide minute-to-minute measurements of \( \text{VO}_2 \), \( \text{VCO}_2 \), RQ and EE

Advantages:
- considered the most accurate:
- validated both in vivo and in vitro (Tissot et al. 1995)

Disadvantages:
- bulky
- technically demanding
- warming up and calibration process are time consuming and costly
- no longer manufactured
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Indirect calorimetry: breath by breath technique

- most well known is the M-COVX
- main difference is the mixing chamber is absent
- measurements are made every breath
- site of gas sampling and volume measurements is usually at the proximal airway
  - D-Lite (flow sensor for adults) in conjunction with the gas sample are connected at the patient’s airway and provide the conduit for the gas exchange measurement
  - flow measurement is based on the pressure across a special proprietary turbulent flow restrictor
  - inside the gas module of the M-COVX a paramagnetic sensor is used to measure the O2 curve and an infrared bench is used for the CO2 curve
Indirect calorimetry: breath by breath technique

Advantages:
- technically less demanding
- performs its own calibration and less time for warming up
- does not require costly commercial gas for calibration

Disadvantages:
- if respiratory rate >35 breaths-per-minute (BPM), sampling speed of the M-COVX is too slow (excludes infants <1yr)
- may be inaccurate in ventilated patients using pressure support mode (Harris 2003)
  - when gas is sampled from a point with fluctuating pressure, fluctuation leads to an unstable concentration of O2
  - the paramagnetic and infrared sensors are triggered by pressure changes in the flow of O₂ and CO₂ leads to inaccurate sampling of VO₂ and VCO₂
- more validation is required for use in ventilated patients
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Indirect calorimetry

- Desk top method e.g. Cosmed fitmate
  - measures $O_2$ consumption only
  - no measurement of $CO_2$ consumption
  - no calculation of RQ
SenseWear Armband

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SenseWare armband

- a physiological monitor
- SenseWare Pro3 Armband uses four sensors:
  - two-axis accelerometer which tracks movement and body position,
  - heat-flux sensor determining heat dissipated from the body by the measurement of heat loss between the skin and a vent on the side of armband,
  - sensitive thermistors which measure skin temperature,
  - sensor that measures galvanic skin response (GSR) which varies due to sweating and emotional stimuli.

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SenseWare armband

- uses data statistical modelling system
  - data from recorded from the 4 sensors
  - subject data; height, weight, age
- BMR derived from more than 90 million x 1 min indirect calorimetry measurements

Advantages:
- accurate measurements of activity, physical stress
- useful in sport

Disadvantage:
- does not measure REE
SenseWear Armband

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BMR equations

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BMR equations

Equations that estimate REE in health:
- Harris Benedict Equations
- Schofield Equations
- Oxford equations

Equations that estimate REE in illness:
- Disease specific equations (e.g., Ireton Jones, Swinamer)
- Weight (kcal/kg)
Schofield Equations

- Developed in the 1980’s for WHO/FAO expert consultation (Schofield 1985)
- Database of 114 studies 7173 subjects
  - North European and American
  - Italian
  - Asians
  - residual mixed group
- Studies carried out 1914→1980 (including HB data)
- SE (Schofield 1985):
  - 153-164kcal/d ♀
  - 108-119kcal/d ♂

- Database of 10,552 BMR values
- Included studies from 1914 to 2005
- More rigorous examination of methodology
- Exclusions:
  - Italian high altitude data
  - excluded malnourished/sick
  - screened data and excluded outliers
- Inclusions:
  - only papers were measurement conditions met criteria for BMR
  - larger numbers of elderly (534m 340w)
Advantages of Henry’s Equations

- Schofield tended to overestimate due mainly to the Italian data:
  - 47% of Schofield database
  - higher BMR/kg than any other group
- Historical measurement of BMR was to diagnose thyroid disorders:
  - Recent data more accurate (measurement of BMR)
- Database contains a more representative sample of the world population.
### Oxford equations (Henry 2005)

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Kcal (day(^{-1}))</th>
<th>SE</th>
<th>n</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-18</td>
<td>18.4W + 581</td>
<td>0.566</td>
<td>863</td>
<td>0.861</td>
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<tr>
<td>18-30</td>
<td>16.0W + 545</td>
<td>0.652</td>
<td>2821</td>
<td>0.760</td>
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<tr>
<td>30-60</td>
<td>14.2W + 593</td>
<td>0.693</td>
<td>1010</td>
<td>0.742</td>
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<tr>
<td>60-70</td>
<td>13.0W + 567</td>
<td>0.697</td>
<td>270</td>
<td>0.766</td>
</tr>
<tr>
<td>70+</td>
<td>13.7W + 481</td>
<td>0.667</td>
<td>264</td>
<td>0.779</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-18</td>
<td>11.1W + 761</td>
<td>0.525</td>
<td>1063</td>
<td>0.752</td>
</tr>
<tr>
<td>18-30</td>
<td>13.1W + 558</td>
<td>0.564</td>
<td>1664</td>
<td>0.700</td>
</tr>
<tr>
<td>30-60</td>
<td>9.74W + 694</td>
<td>0.581</td>
<td>1023</td>
<td>0.690</td>
</tr>
<tr>
<td>60-70</td>
<td>10.2W + 572</td>
<td>0.476</td>
<td>185</td>
<td>0.798</td>
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<tr>
<td>70+</td>
<td>10.0W + 577</td>
<td>0.518</td>
<td>155</td>
<td>0.746</td>
</tr>
</tbody>
</table>
Application of energy expenditure measurement to the research setting