What is a calorie?
Are all calories bio-available?
Are all calories metabolically equal?

Genie Moore, PhD
What is a calorie?

- The amount of energy needed to increase the temperature of 1 g of water from 14.5° to 15.5°C
How much energy is a kcal?

- Women usually use slightly <1 kcal/min and men use slightly more
  - One kcal/min corresponds approximately to the heat released by a burning candle or by a 75-watt light bulb (i.e., 1 kcal/min corresponds to 70 J/sec or 70 W)
How are kcal in food measured?

- Bomb calorimetry was used historically and is still widely used.
Metabolizable energy

The difference between gross energy in consumed food (determined by bomb calorimetry) and energy in feces and urine (also measured by bomb calorimetry)

- Rubner: heat of combustion of protein in a bomb calorimeter is higher than the energy value available to the host
  - Protein oxidized in vivo to urea, creatinine, uric acid, and other nitrogenous end products
  - \( \approx 23\% \) of energy from protein lost in urine and feces
- Atwater and Bryant extended Rubner’s observation to other nutrients
## Atwater factors

<table>
<thead>
<tr>
<th>Macronutrient</th>
<th>Heat of combustion</th>
<th>Coefficient of availability</th>
<th>Available energy</th>
<th>(kcal/g) total nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>5.65</td>
<td>92</td>
<td></td>
<td>4.0^1</td>
</tr>
<tr>
<td>Fat</td>
<td>9.40</td>
<td>95</td>
<td></td>
<td>8.9</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>4.10</td>
<td>97</td>
<td></td>
<td>4.0</td>
</tr>
</tbody>
</table>

^1 Corrected for unoxidized material in the urine, i.e., \((5.65 \text{ kcal/g} \times 0.923) - 1.25 \text{ kcal/g}\).
Intake with mixed diet vs alone

- Atwater factors
  - From subjects eating a single food
  - General
    - 4, 9, 4 kcal/g (pro, fat, CHO)
    - Deduct insoluble fiber
    - Used on food labels
  - Specific
    - Digestibility of particular food (nuts)
    - 3.47, 8.37, 4.07 kcal/g

- Empiric
  - Measured as part of a mixed diet

Factors affecting available energy

- Characteristics of the diets
  - Refined vs unrefined
  - Specific nutrient composition
- Loss of ingested energy
- Environmental factors
- Characteristics of the subject or the model chosen
Diet characteristics
Diet formulations

- Cereal-based, unrefined, or nonpurified
  - Composed predominantly of unrefined plant and animal ingredients

- Purified
  - Composed primarily of purified commercially-available proteins, carbohydrates, and fats with vitamins and minerals added

- Chemically defined
  - Composed of chemically pure nitrogen, carbohydrate, fat, vitamin, and mineral sources
Choice of diet affects gene expression in mouse liver

- Nonpurified diet (Lab Rodent Diet-5001) vs purified (AIN-76a)
- Gene categories affected: 132 including those involved in
  - Fatty acid metabolism
  - Glycolysis/glucoreogenesis
  - Starch and sucrose metabolism
  - Ketone synthesis and degradation
  - PPAR signaling
  - Amino acid metabolism

Loss of ingested energy

- Renal threshold
- Incomplete absorption
  - Fiber content of diet
    - Amount of fermentation
    - Trapping of other nutrients
  - Resistant starch
  - Fructose
  - Very high fat
Cecum in various species

Opossum  Kangaroo  Koala

Human  Rabbit  Zebra
Resistant starch

- Indigestible by body enzymes
  - Physically inaccessible
    - Partially milled grains and seeds
  - Ungelatinized resistant granules, slowly degraded by amylase
    - Raw potato, green bananas, some legumes
  - Retrograded starch
    - Cooked and cooled potato, pasta
Fructose absorption in healthy adults

Data compiled by Jones H F et al. Am J Physiol Gastrointest Liver Physiol 2011;300:G202-G206

$r = 0.86, P < 0.001$
Facultative thermogenesis

- Thermoneutral environment for mice $\approx 30$-$32^\circ$C (HR 350-400 bpm)$^1$
  - Normally housed at 21-23$^\circ$C (HR 550–600 bpm)

Diet-induced thermogenesis

- Energy required for digesting, absorbing, and assimilating food

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$^1$ Swoap S et al. AJP 286:R108, 2004
Feed Efficiency

- Definition: food intake ÷ weight gain

- Impacted by
  - Age
  - Sex
  - Season
  - Stage of reproduction
  - Behavior and activity
  - Temperature
  - Humidity
  - Heredity
    - Estimates in mice range from 0.1 to 0.56 heritability
Some nutrients have unexpected impact on energy metabolism

- Fructose
- Fats of different chain length
Metabolism of fructose

Tappy L and Le K. Physiol Rev 90:23, 2010
Trends in high fructose corn syrup consumption and overweight/obesity in the U.S.

[Graph showing trends in HFCS consumption and overweight/obesity]

Glucose and insulin in women consuming either high glucose or high fructose feedings

Fructose or glucose = 25% of kcal for 10 weeks.
Change in body weight and fat in women consuming glucose or fructose

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ compared with baseline

Degree of fatty acid saturation: impact on effect of a HF diet

- Hypothesis: a high fat diet rich in saturated fat will result in more weight gain than a similar diet rich in mono- or polyunsaturated fats
  - Saturated fat will be associated with greater hypothalamic inflammatory state and insulin resistance than unsaturated fat

Courtesy of KP Rogers
Food intake during consumption of diets with different fat sources
Cumulative change in body weight

Cumulative Weight Gain (g)
High saturated fat diet resulted in less weight gain than the “mixed” high fat diet, in spite of similar kcal intakes.

Why?

Primary source of saturated fat was coconut oil

- Coconut oil = 92% saturated fat
- But 2/3 of the saturated fat consists of medium chain fatty acids
Medium chain fatty acid metabolism
Metabolism of fatty acids in the liver

TG = triacylglycerols; PL = phospholipids; CE = cholesterol esters
Energy impact of MCT substituted for LCT

Replacement of dietary LCT for MCT

- Increased EE (460 kJ/d)
- Increased satiety (175-698 kJ/meal)

- Negative energy balance
- Decreased food intake

- Prevention of body weight gain

460 kJ = 110 kcal
175-698 kJ = 42-167 kcal

3 LOW-CARB WEEKS TO A SLimmer YOU

THE COCONUT DIET

The SECRET INGREDIENT That Helps You LOSE WEIGHT While You Eat Your Favorite Foods

Cherie Calbom, author of The Planud Anointer Book

with John Calbom
Characteristics of the tissue deposited

- **Fat tissue**
  - Fat has $\approx 9.4$ kcal/g
  - Adipose tissue is $\approx 20\%$ water
  - 1 g adipose tissue contains $\approx 7.5$ kcal
    - Cost of depositing fatty acids in adipose is almost 0 kcal

- **Lean tissue**
  - Protein has $\approx 4$ kcal/g
  - Lean tissue is $\approx 80\%$ water
  - 1 g lean tissue = 0.8 kcal
    - 1 g lean tissue requires 1 kcal for synthesis
    - Total energy needed for 1 g lean tissue = 1.8 kcal
Characteristics of the model chosen

Adult mice consuming water ± fructose for 40 days

- Strain: AKR 129P3 B6 FVB
- Standardized fat pad weight (g): 0.0, 0.2, 0.4, 0.6, 0.8
- Sum of the wts of mesenteric, retroperitoneal and perigonadal fat pads in mice consuming 34% fructose (P<0.05 for effect of strain)

Glendinning J et al. Physiol Behav. 2010 Oct 5;101(3):331-43
Metabolizable energy: why doesn’t what goes in always equal what goes out?

- Inaccurate assessment of metabolizable energy
  - Fecal losses
    - High fat intake
    - High fiber intake
    - Resistant starches
  - Other unassessed losses
    - Exceeding the renal threshold
- Unassessed changes in activity/thermogenesis
- Energy costs of depositing different tissues
Conclusion

- All calories are equal – at least in terms of energy of combustion
- Not all calories yield the same energetic and metabolic effects *in vivo*