“Scientific truth does not triumph by convincing opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it… Science progresses funeral by funeral.”

Max Planck
What makes the World go ‘round?
E = mc²

ENERGY
All movement requires energy
Life cannot exist without energy
All organisms must obtain energy.
Unprovoked Shark Attacks in the USA and Florida 1960-2011 (N=1,003)
Heliotropism
Movement = Energy Expenditure (EE)
Reciprocal Relationship:

EI requires EE

EE requires EI
Natural Selection:

Organisms that maximize energy intake and minimize energy expenditure survive.
But what is energy?
Energy

- From Greek: ‘energeia’
  - ‘activity’ or ‘operation’

- Quantitative (measured) property describing the state of a physical object or system

- "To measure is to know." Lord Kelvin (Sir William Thomson)
Energy

- Many classifications of energy: heat, kinetic, electromagnetic, radiant, nuclear and chemical
- Energy can be converted from one form to another but not destroyed
- Chemical and Heat
Organic Chemical Energy

- Solar energy is converted via photosynthesis (plants, algae, cyanobacteria) to synthesize organic compounds
  - e.g., carbohydrates, proteins, lipids
  - Consumed by other organisms

- Rubner (1894): application of laws of Thermodynamics to biological organisms

- Metabolism of organic matter $\rightarrow$ \( CO_2 + H_2O + \) energy
Energy Units

- Joule (J): The SI unit of energy/work/heat.
- KJ = kilojoule; MJ = Megajoule
- calorie = amount of energy required to raise the temperature of 1 g water 1°C

- 1 Calorie = 1000 calories = 1 kcal
- 1 kcal = 4.184 J
- 1 kJ = .239 kcals
Partitioning of Dietary Energy Intake

Intake Energy (Gross)

Digestible Energy

Metabolizable Energy

Net Energy

Surplus Energy

Excretory (Fecal) loss

Urine, Gas

Nutrient Metabolism & Microbial Fermentation

BMR & PAEE & AT: Maintenance, Activity

Growth, Net Fat deposition, Re/production
# Food Energy/Atwater Values

<table>
<thead>
<tr>
<th>Food component</th>
<th>Energy density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kJ/g</td>
</tr>
<tr>
<td>Fat</td>
<td>37</td>
</tr>
<tr>
<td>Ethanol (drinking alcohol)</td>
<td>29</td>
</tr>
<tr>
<td>Proteins</td>
<td>17</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>17</td>
</tr>
</tbody>
</table>

Metabolizable Energy = (Gross Energy) – (Energy losses in feces, urine, secretions & gas)
Atwater Factors vs. Atwater ‘Specific’ Factors

- Refinement based on re-examination of the Atwater system introduced in 1955

- Demonstrated substantial variability in the energy factors applied to various foods
  - PRO: 3.75-4.55 kcal/g
  - CHO: 2.45-4.20 kcal/g
  - *FAT: 9.3-9.5 kcal/g
**Net Metabolizable Energy (NME)**

**Table 1.** Gross intake (IE), digestible (DE), metabolisable (ME) and net metabolisable energy (NME) factors for important food components and the prediction of specific food NME values (for factors for other components, see Independent Nutrition Logic, 2000)

<table>
<thead>
<tr>
<th></th>
<th>IE*</th>
<th>DE*</th>
<th>ME*</th>
<th>NME</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat (F; g)</td>
<td>39.3</td>
<td>37.4</td>
<td>37.4</td>
<td>36.6</td>
<td>kJ/g ingested F</td>
</tr>
<tr>
<td>Protein (P; g)</td>
<td>23.6</td>
<td>21.5</td>
<td>16.7</td>
<td>13.3</td>
<td>kJ/g ingested P</td>
</tr>
<tr>
<td>Available CHO (AC; g)†</td>
<td>15.7</td>
<td>15.7</td>
<td>15.7</td>
<td>15.7</td>
<td>kJ/g ingested AC as monosaccharide</td>
</tr>
<tr>
<td>Dietary fibre (DF; g)</td>
<td>17</td>
<td>7.8</td>
<td>7.8</td>
<td>6.2</td>
<td>kJ/g ingested DF†</td>
</tr>
<tr>
<td>Fermentable†</td>
<td>17</td>
<td>11</td>
<td>11</td>
<td>8</td>
<td>kJ/g ingested fermentable DF</td>
</tr>
<tr>
<td>Non-fermentable†</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>kJ/g ingested non-fermentable DF</td>
</tr>
<tr>
<td>Alcohol (Alc)</td>
<td>29.4</td>
<td>29.4</td>
<td>28.8</td>
<td>26.4</td>
<td>kJ/g ingested Alc</td>
</tr>
</tbody>
</table>

Food energy (ME; kJ) = 37 F + 17 P + 16 AC + 8 DF + 29 Alc (rounded from 37.4 F + 16.7 P + 15.7 AC + 7.8 DF + 29.4 Alc).

Food energy (NME; kJ) = 37 F + 13 P + 16 AC + 6 DF + 26 Alc (rounded from 36.6 F + 13.3 P + 15.7 AC + 6.2 DF + 26.4 Alc).

* From Merrill & Watt (1973), using their IE, digestibilities and urinary energy loss (5.2 kJ/g digestible N) and energy loss in breath (2% energy losses from alcohol as volatile substances in breath and urine).

† NME and ME values also applicable to isolates of NSP, resistant starch oligosaccharides and sugar alcohols.

‡ For traditional foods this can be Southgate (1969) dietary fibre, Association of Official Analytical Chemists (Prosky et al. 1988) dietary fibre or the sum of NSP and associated resistant starch when it is <20% of non-starch polysaccharide.

NME vs. ME

Fig. 3. Over-estimation of the isodynamc equivalents for energy expenditure and energy balance (net metabolisable energy; NME) by the (metabolisable energy; ME) standard when applied to 1189 foods in the British food tables, due to protein and unavailable carbohydrate. ME of foods was calculated using available carbohydrate as monosaccharide (15.7 kJ (3.75 kcal) ME/g), fat (37 kJ (9 kcal) ME/g), protein (16.7 kJ (4 kcal) MEkJ/g), dietary fibre (8.4 kJ (2 kcal) ME/g), alcohol (29 kJ (7 kcal) ME/g) and appropriate factors for organic acids. NME was calculated by replacing the ME factors for protein and dietary fibre with NME factors from the British Nutrition Foundation (1990) report: 13 kJ (3.2 kcal) NME/g and 6.2 kJ (1.5 kcal) NME/g respectively. For the present illustration dietary fibre was Southgate (1969) dietary fibre.

## Energy values of human milk


<table>
<thead>
<tr>
<th>Composition</th>
<th>ME-ATW g/liter</th>
<th>ME-specific g/liter</th>
<th>NME g/liter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME-ATW kJ/ml</td>
<td>ME-specific kJ/ml</td>
<td>NME kJ/ml</td>
</tr>
<tr>
<td></td>
<td>(kcal/ml)</td>
<td>(kcal/ml)</td>
<td>(kcal/ml)</td>
</tr>
<tr>
<td>Protein</td>
<td>8.9</td>
<td>0.15</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Fat</td>
<td>32</td>
<td>1.18</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.28)</td>
<td>(0.29)</td>
</tr>
<tr>
<td>CHO-lactose/glucose</td>
<td>74</td>
<td>1.26</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.29)</td>
<td>(0.28)</td>
</tr>
<tr>
<td>Energy</td>
<td>2.59</td>
<td>2.55</td>
<td>2.48</td>
</tr>
<tr>
<td></td>
<td>(0.63)</td>
<td>(0.61)</td>
<td>(0.60)</td>
</tr>
</tbody>
</table>

Δ20-30%  
Δ3-7%  
Δ3-5%
Take Home Message

- Energy content depends on
  - Type of organic matter (food, etc.)
- Energy content is not constant across macronutrients or foods
- Macronutrient substitutions via Atwater Factors are not energy equivalents
- Site of energy conversions
  - E.g., AA to CHO: Gluconeogenesis
  - CHO to CHO: Glycogenogenesis

Macronutrient Substitutions?

- Differential Heat Energy Expenditure (dHE) when CHO are replaced by other energy substrates.

- To be accurate, the assessment of food energy should take account of the site of energy conversion.

Research Data

- **Quantitative**
  - Based on objective properties
  - Direct & Measurable

- **Qualitative**
  - Based on subjective properties
  - Perceptions: not directly measurable

- **Pseudo-quantitative**
  - Assigning numeric values to qualitative data
Dietary Recall to Dietary Energy Translation

Data Collection

24HR, FFQ, Food Diaries

Data Processing

NNBS Database

Translation of Data

Data Analysis: Researcher

Potential Errors:
Mis-reporting, Under/over eating

Inaccurate/Incomplete Database

Confounding by Known or Unknown Factors
Summary of Biases & Issues

- Misreporting
- Under-reporting
- Over-reporting
- Assigning caloric values to what the participant is willing and able to recall about what they think they ate yesterday
- Inadequate or incomplete database
Human Nature

- Poor at observing their own behavior
- What little is observed is not remembered accurately
- What little is remembered is not described accurately
- What is described is simplified
- Dietary Recall: Simplified, inaccurate description of poorly observed & remembered eating behaviors

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Abstract

Importance: Methodological limitations compromise the validity of U.S. nutritional surveillance data and the empirical foundation for formulating dietary guidelines and public health policies.

Objectives: Evaluate the validity of the National Health and Nutrition Examination Survey (NHANES) caloric intake data throughout its history, and examine trends in the validity of caloric intake estimates as the NHANES dietary measurement protocols evolved.

Design: Validity of data from 28,993 men and 34,369 women, aged 20 to 74 years from NHANES I (1971–1974) through NHANES 2009–2010 was assessed by: calculating physiologically credible energy intake values as the ratio of reported energy intake (rEI) to estimated basal metabolic rate (BMR), and subtracting estimated total energy expenditure (TEE) from NHANES rEI to create ‘disparity values’.

Main Outcome Measures: 1) Physiologically credible values expressed as the ratio rEI/BMR and 2) disparity values (rEI–TEE).

Results: The historical rEI/BMR values for men and women were 1.31 and 1.19, (95% CI: 1.30–1.32 and 1.18–1.20), respectively. The historical disparity values for men and women were −281 and −365 kilocalorie-per-day, (95% CI: −299, −264 and −378, −351), respectively. These results are indicative of significant under-reporting. The greatest mean disparity values were −716 kcal/day and −856 kcal/day for obese (i.e., ≥30 kg/m²) men and women, respectively.

Conclusions: Across the 39-year history of the NHANES, EI data on the majority of respondents (67.3% of women and 58.7% of men) were not physiologically plausible. Improvements in measurement protocols after NHANES II led to small decreases in underreporting, artifactual increases in rEI, but only trivial increases in validity in subsequent surveys. The confluence of these results and other methodological limitations suggest that the ability to estimate population trends in caloric intake and generate empirically supported public policy relevant to diet-health relationships from U.S. nutritional surveillance is extremely limited.
Method

- Examined 39 Years of NHANES data
  - 28,993 men and 34,369 women, aged 20 to 74 years
- “Physiologically Plausible” Reporters
- Biologically Possible to Survive
Method

- Reported Energy Intake (rEI) ÷ Basal Metabolic Rate (BMR)
  - aka: “Goldberg cutoff”
  - Expected value ~1.55
  - <1.35 or >2.40 = Implausible
Method: Example

- $rEI \div BMR$
- $1500/1000 \text{ kcals}$
- $\text{Ratio} = 1.5$
  - Plausible
- $1000/1000 \text{ kcals}$
- $\text{Ratio} = 1.0$
  - Implausible
Method

- $rEI \div BMR$
- Expected value $\sim 1.55$
- $<1.35$ or $>2.40 = $ Implausible
- $<1.35 = $ Confined to bed, no activity
- $>2.40 = $ Arctic explorer X-country skiing while dragging a sled 10 hrs/day
The Mean rEI/BMR Values

- Men: 1.31
- Women: 1.19
- Obese Men: 1.21
- Obese Women: 1.10

- Expected value of Comatose patient with an IV drip
- ~50% of obese women reported lower values
Method #2

- Institute of Medicine
  - Total Energy Expenditure Predictive equations
  - Based on Objective database
- \( rEI - TEE = \text{Disparity value} \)
  - Negative values = underreporting
Disparity Values

- Men: -281 kilocalorie-per-day
- Women: -365 kcal/d
- Obese Men: -467.4 kcal/d
- Obese Women: -553.5 kcal/d
Over-reporting: rEI/BMR > 2.40

- 4.9% of men
  - High of 6.4% NHANES III

- 2.9% of women
  - 3.9% in NHANES 2003-2004
Correlations with IOM TEE

- Men: 0.225
- Women: 0.163

- Correlation of 1.0 is perfect
- 0.7 = acceptable
- 0.5 = marginal
- < 0.25 = No meaningful relationship
Validity of NHANES

“Across the 39-year history of the NHANES, EI data on the majority of respondents (67.3% of women and 58.7% of men) were not physiologically plausible.”

Archer et al., PLoS ONE 2013;8(10): e76632
Previous Research

- Goldberg et al. (1991)
- 37 studies across 10 countries
- >65% of the mean rEI/BMR values were implausible
- Study specific cutoff
- Plural of anecdote is not data
<table>
<thead>
<tr>
<th>Nutrient</th>
<th>1 FFQ</th>
<th>2 FFQ</th>
<th>1 24HR</th>
<th>4 24HR</th>
<th>14 24HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein</td>
<td>.14/.30</td>
<td>.16/.32</td>
<td>.14/.29</td>
<td>.32/.44</td>
<td>.46/.53</td>
</tr>
</tbody>
</table>
I gather inaccurate data for a living. Luckily no one uses it.

Your glass is half full.
Nutrition & Obesity

- Numerous unscientific statements about nutrition, obesity, and health.

- “… Americans continued to consume an average of 3800 calories per person per day, or about twice the daily requirement.”


Edward Archer, PhD, MS; Gregory A. Hand, PhD, MPH; James R. Hébert, ScD, MSPH; Erica Y. Lau, MPhil; Xuewen Wang, PhD; Robin P. Shook, PhD, MS; Raja Fayad, MD; Carl J. Lavie, MD; and Steven N. Blair, PED
Components of Total Daily Energy Requirements (TDEE)

- RMR = 60%
- AT = 30%
- TEF = 10%
Components of Resting Metabolic Rate (RMR)

- Liver: 19%
- Brain: 18%
- Heart: 10%
- Kidneys: 7%
- Skeletal Muscle: 19%
- Other Organs: 27%
Estimating Energy Expenditure

- *A Priori* assumption: EI = EE
- Total daily EE (TEE)
  - TEE = BMR x APAR x TEF x AT
- BMR: Mifflin-St. Joer equation
- APAR: Accelerometry based physical activity monitors
- TEF: Constant 7.5% of TEE
- AT: Ignored
Nationally Representative Estimates

- Men: 2940 kcal/day
- Women: 2275 kcal/day
- Range:
  - 3230 kcal/day in obese men
    - (BMI $\geq 30$ kg/m$^2$)
  - 2026 kcal/day in normal-weight women
    - (BMI $< 25$ kg/m$^2$).
Validation via IOM TEE

- 0.98 correlation w/ IOM TEE
- Absolute estimates higher in all individuals

Range
- Low: 46 kcal/d (1.3%) in obese men
- High: 178 kcal/d (6.8%) in obese women.
Summary

- No valid data on population-level energy intake exist.

- “the ability to estimate...trends in caloric intake and generate empirically supported public policy...from U.S. nutritional surveillance is extremely limited.”

Archer et al., PLoS ONE 2013;8(10): e76632
“The reasonable man adapts himself to the world: the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man.”

George Bernhard Shaw
Thanks!

Questions?!?!