Monkey Microbes and Human Health:
Putting health disparities into an evolutionary context

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Gut microbiota

Nutrition

Immune function

Mental state
The Gut Microbiota

- Implicated in:
  - Hypertension
  - Asthma
  - Cardiovascular Disease
  - Obesity
  - Cancer
  - And more...
Health Disparities

• Apparent in:
  – Hypertension
  – Asthma
  – Cardiovascular Disease
  – Obesity
  – Cancer
  – And more...
How important are gut microbes for understanding patterns of health inequality across populations?
Figure 1. Prevalence of obesity among children and adolescents aged 2–19 years, by poverty income ratio, sex, and race and ethnicity: United States, 2005–2008

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.9</td>
<td>12.0</td>
</tr>
<tr>
<td>Non-Hispanic white</td>
<td>10.2</td>
<td>10.6</td>
</tr>
<tr>
<td>Non-Hispanic black</td>
<td>12.5</td>
<td>12.0</td>
</tr>
<tr>
<td>Mexican American</td>
<td>22.9</td>
<td>21.0</td>
</tr>
</tbody>
</table>

+Significant trend.

NOTES: PIR is poverty income ratio. Persons of other race and ethnicity included in total.

An obesity-associated gut microbiome with increased capacity for energy harvest

Peter J. Turnbaugh¹, Ruth E. Ley¹, Michael A. Mahowald¹, Vincent Magrini², Elaine R. Mardis¹,² & Jeffrey I. Gordon¹
Increased SCFA Production

→ More Energy to Host
Gut Microbes Compensate Across Seasons

F$_{2,38}$ = 3.56, r$^2$ = 0.14, p = 0.0002

Amato et al. 2015, Microbial Ecology
Gut Microbes Compensate For Life History

• Juveniles
  – Characterized by Firmicutes (*Faecalibacterium, Roseburia, Ruminococcus*)

• Adult Females
  – High Firmicutes:Bacteroidetes ratio
  – Characterized by *Lactococcus*

Amato et al. 2014, AJPA
Do these apparently beneficial relationships break down?
Gut Microbes Degraded With Habitat Disturbance

Amato et al. 2013, ISME J
Gut Microbes Degraded With Habitat Disturbance

Amato et al. 2013, ISME J
Gut Microbes Degraded With Habitat Disturbance

Amato et al. 2013, ISME J
Extreme Case: Captivity in Primates

Amato et al. 2016, GECCO

Frankel et al. in prep
Captivity humanizes the primate microbiome

Jonathan B. Clayton\textsuperscript{a,b}, Pajau Vangay\textsuperscript{c}, Hu Huang\textsuperscript{d}, Tonya Ward\textsuperscript{d}, Benjamin M. Hillmann\textsuperscript{e}, Gabriel A. Al-Ghalith\textsuperscript{c}, Dominic A. Travis\textsuperscript{f}, Ha Thang Long\textsuperscript{g,h}, Bui Van Tuan\textsuperscript{h}, Vo Van Minh\textsuperscript{i}, Francis Cabana\textsuperscript{j}, Tilo Nadler\textsuperscript{k}, Barbara Toddes\textsuperscript{l}, Tami Murphy\textsuperscript{m}, Kenneth E. Glander\textsuperscript{n}, Timothy J. Johnson\textsuperscript{o}, and Dan Knights\textsuperscript{p,q,r,s}

\textsuperscript{a}Department of Veterinary and Biomedical Sciences, University of Minnesota, Saint Paul, MN 55108; \textsuperscript{b}GreenViet Biodiversity Conservation Center, Danang 59000, Vietnam; \textsuperscript{c}Bioinformatics and Computational Biology, University of Minnesota, Minneapolis, MN 55455; \textsuperscript{d}Biotechnology Institute, University of Minnesota, Saint Paul, MN 55108; \textsuperscript{e}Department of Computer Science at Veterinary Population Medicine, University of Minnesota, Saint Paul, MN; \textsuperscript{f}Environment and Biology, Danang University of Education, Danang 5901 Singapore; \textsuperscript{g}Endangered Primates Rescue Center, Cuc Phuong National Park, Philadelphia, PA 19108; \textsuperscript{h}Como Park Zoo & Conservatory, Saint Paul, MN 55108

\begin{center}
\includegraphics[width=\textwidth]{figure}
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GI Health Status

- Healthy
- Unhealthy
- Uncertain

Host Genus
- Douc
- Langur
- Colobus

Unweighted Unifrac
- Weighted Unifrac

Amato et al. 2016, GECCO
Not just diet...

Weighted UniFrac ($F_{1,51}=5.01$, $r^2=0.09$, $p<0.01$)

Sample Location and Age
- (18) Cayo: Adult
- (9) Cayo: Juvenile
- (15) SS: Adult
- (10) SS: Juvenile

Amato et al. in prep
Probably...but we need more data

*Seasonal variation in human gut microbiome composition.*
Davenport ER¹, Mizrahi-Man O¹, Michelini K¹, Barreiro LB¹, Ober C¹, Gilad Y¹.

*Seasonal cycling in the gut microbiome of the Hadza hunter-gatherers of Tanzania.*
Smits SA¹, Leach J², Sonnenburg ED¹, Gonzalez CG⁴, Lichtman JS⁴, Reid G⁵, Knight R⁶, Manjurano A⁷, Chagulucha J⁷, Elias JE⁴, Domínguez-Bello MG⁸, Sonnenburg JL¹.

*Host remodeling of the gut microbiome and metabolic changes during pregnancy.*
Koren O¹, Goodrich JK, Cullender TC, Spor A, Laitinen K, Bäckhed HK, Gonzalez A, Werner JJ, Angenent LT, Knight R, Bäckhed F, Isolauri E, Salminen S, Ley RE.
Industrialization and the Gut Microbiota

Schnorr et al. 2014, Martinez et al. 2015, Clemente et al. 2015
What about mismatch situations?
An obesity-associated gut microbiome with increased capacity for energy harvest

Peter J. Turnbaugh¹, Ruth E. Ley¹, Michael A. Mahowald¹, Vincent Magrini², Elaine R. Mardis¹,² & Jeffrey I. Gordon¹
Fig. 7.1 Age-standardized prevalence of obesity in men aged 18 years and over (BMI ≥30 kg/m²), 2014

Prevalence of obesity (%)*

- <5
- 5–14.9
- Data not available
- 15–24.9
- Not applicable

* BMI ≥ 30 kg/m²
Hossain et al. 2007
Major Questions

• Does a maternal history of undernutrition in early life lead to an energy-efficient gut microbiota in adulthood?

• Can these microbial traits be passed to infants and affect health outcomes (particularly if the nutritional environment shifts)?
The Cebu Study

The Cebu Longitudinal Health & Nutrition Survey

3327 pregnant women enrolled (1983)

Birth

Mothers

Offspring

Grandoffspring

Data collection on full sample

1983-4 preg & birth

1984-6 infancy

1991 childhood

1994 puberty

1998-9 young adult

2000

2005

2017
Mom
Final Thoughts

• To understand what is ‘wrong’ with the microbiome when there are health issues, we need to:
  – Understand what was evolutionarily ‘right’
  – Understand what perturbations have altered the system

• Studies of human populations are critical

• Non-human primates give us an even broader context
Thank you!