Determinants and Health Impacts of PFAS Exposures in Humans

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Disclaimers

- I have no financial conflicts of interest
Outline

- Source of PFAS Exposure
  - Relative contributions
  - Water
  - Food
  - Other media

- Health Effects of PFAS Exposure in Humans
  - Fetal growth
  - Child/adult adiposity
  - Breastfeeding
Perfluoroalkyl Substances (PFAS)

- Persistent chemical compound used in commercial products and industrial applications
  - Carpet, textiles, leather, paper, cardboard, food packaging, electronics, cleaning agents, cosmetics, firefighting foams
- Perfluorooctanoate (PFOA) & perfluorooctane sulfonate (PFOS) commonly detected in serum
  - Half-life of 3-7 years
- Concern over effects on fetal, infant, and child health
- 2016 EPA drinking water advisory level set to 70 ppt (ng/L)
  - Cumulative
Sources of PFAS Exposure
PFAS Exposure in Adults

- General population primarily exposed by ingesting contaminated food, water, or dust
- Diet is predominant route of exposure for adults

<table>
<thead>
<tr>
<th>Daily Intake (pg/kg b.w.)</th>
<th>Mean</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFOA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor Air</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Outdoor Air</td>
<td>1.3</td>
<td>12.0</td>
</tr>
<tr>
<td>House Dust</td>
<td>16.4</td>
<td>1028.3</td>
</tr>
<tr>
<td>Diet</td>
<td>2816.7</td>
<td>11483.3</td>
</tr>
<tr>
<td>Drinking water</td>
<td>21.7</td>
<td>86.7</td>
</tr>
<tr>
<td><strong>Overall intake</strong></td>
<td><strong>2857.0</strong></td>
<td><strong>12611.2</strong></td>
</tr>
<tr>
<td><strong>PFOS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor Air</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Outdoor Air</td>
<td>.01</td>
<td>1.0</td>
</tr>
<tr>
<td>House Dust</td>
<td>31.7</td>
<td>4216.7</td>
</tr>
<tr>
<td>Diet</td>
<td>1500.0</td>
<td>4483.3</td>
</tr>
<tr>
<td>Drinking water</td>
<td>23.2</td>
<td>130.0</td>
</tr>
<tr>
<td><strong>Overall intake</strong></td>
<td><strong>1559.8</strong></td>
<td><strong>8835.7</strong></td>
</tr>
</tbody>
</table>

Fromme et al. 2009, Mogensen et al. 2015.
PFOS Exposures in Children

2-Year Old Children

Adult

- After weaning, PFAS sources likely to be similar to that of adults
- However, breast milk is a major source of exposure in infants . . .

Egeghy and Lorber 2011
Breastfeeding and PFAS

- Haug et al. (Envr Int, 2011) estimates that breastmilk represents majority of PFOA (83%) and PFOS (94%) exposure in infants
  - Infant intakes were 13 to 16-fold greater than adults

- Mogensen et al. (ES&T, 2015):
  - Exclusively breastfed infants had 30% greater PFOA/PFOS concentrations compared to non-breastfed infants

<table>
<thead>
<tr>
<th>Person</th>
<th>PFOA (ng/kg/d)</th>
<th>PFOS (ng/kg/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>4.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Adult</td>
<td>0.26</td>
<td>0.62</td>
</tr>
</tbody>
</table>
Water PFAS

- Drinking water could be a major source in communities with contaminated water supplies.
Comparing Water-Serum PFOA

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Location</th>
<th>Water Source</th>
<th>Median</th>
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</thead>
<tbody>
<tr>
<td>Emmett et al. 2006</td>
<td>291</td>
<td>Parkersburg, WV</td>
<td>Public/Private</td>
<td>105</td>
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<tr>
<td>Hoffman et al. 2011</td>
<td>108</td>
<td>Parkersburg, WV</td>
<td>Private</td>
<td>142</td>
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<tr>
<td>Hoffman et al. 2011</td>
<td>N/A</td>
<td>PK model</td>
<td>N/A</td>
<td>114</td>
</tr>
<tr>
<td>Hurley et al. 2016</td>
<td>1,566</td>
<td>California</td>
<td>Public</td>
<td>145</td>
</tr>
</tbody>
</table>

- Rule of thumb:
  - Serum PFOA ($\mu$g/L) = 125 x Water PFOA ($\mu$g/L)
- Note, there are a range of values, and individuals could be higher or lower
- Ratio for PFOS is ~ 175
Comparing Water-Serum PFAS

- 1 µg/L increase in water PFOA associated with 142 µg/L increase in serum PFOA

<table>
<thead>
<tr>
<th>Water PFOA (µg/L)</th>
<th>Serum PFOA (µg/L)</th>
<th>NHANES Percentile (2011-12)</th>
<th>NHANES Percentile Preg ♀ 2003-08</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015</td>
<td>2.1</td>
<td>~50&lt;sup&gt;th&lt;/sup&gt;</td>
<td>~25&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.03</td>
<td>4.2</td>
<td>~90&lt;sup&gt;th&lt;/sup&gt;</td>
<td>~75&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.07</td>
<td>9.9</td>
<td>&gt;95&lt;sup&gt;th&lt;/sup&gt;</td>
<td>&gt;95&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Dietary PFAS

- Detected in many foods (milk, butter, meats, fish, & vegetables)
  - PFOA less bio-accumulative in fish than PFOS
  - For some PFAS, precursors may be important (e.g., PFHxS)

- NHANES study did not report expected relations between diet and serum PFAS
  - Reasons?

Dietary PFAS: Packaging

- PFAS used in paper and paperboard as water and oil repellants
  - Fast food wrappers, microwave popcorn, and pizza box liners

- Breakdown of precursors in food packaging (Fromme et al., 2009)
  - FDA banned PFAS from food contact in 2016 (81 CFR 5)
Other Potential PFAS Exposures

- Washburn et al. 2005 evaluated PFOA in:
  - Treated/milled carpets, treated apparel, PTFE tape, cookware, and woven medical garments
- Low potential for exposure
- Assuming aggregate exposures, <0.5 ng/mL increase in serum PFOA
Conclusions about Sources of PFAS

- Relative contribution of different media will vary by many factors
  - Age: Infants > adults
  - Geography: Water contamination vs. none
  - Relative contributions vary: Dust

- Public health messaging:
  - Balanced diet (i.e., hedging)
  - GAC water filtration
  - Wet mopping, remove PFAS containing textiles
PFAS and Human Health
PFOA/PFOS and Fetal Growth

- Consistent animal & human evidence that PFOA (maybe PFOS) exposure associated with reduced birth weight
  - 19 gram decrease in BW per 1 ng/mL increase in serum PFOA (95% CI: -30, -7)
  - 23 mg decrease in pup birth weight (95% CI: -29, -16) for each 1 mg/kg/d increase in PFOA exposure

Koustas et al., EHP, 2014; Johnson et al., EHP 2014
PFAS and Child/Adult Adiposity

- Prenatal PFOA/PFOS associated with excess adiposity in some, but not all studies
- Cohort of 700+ US mom-child pairs:
  - Prenatal PFOA/PFOS associated with multiple measures of adiposity at 8, but not 3 years of age
- Cohort of 664 Danish mom-adult pairs
  - Prenatal PFOA associated with higher BMI/WC at 20 years of age
  - Stronger associations in females

Prenatal PFAS and Child Growth

- Could exposure-related reductions in BW be responsible for excess adiposity later in life?
- Rapid growth in 1\textsuperscript{st} 3 years of life associated with increased adiposity at 6-10 years of age
- Rapid growth also associated with risk of cardiometabolic disease
  - Increased blood pressure, triglycerides, LDL, insulin resistance, and central adiposity

Difference in BMI from 2 to 8 Years (n=285, 1,012 visits)

T1: 0.12; CI: -0.08, 0.32
T2: 0.44; CI: 0.23, 0.64
T3: 0.37; CI: 0.14, 0.60
T2 x age p=0.03
T3 x age p=0.11

Braun et al., Obesity, 2015
PFAS and Breastfeeding

- PFOA/PFOS exposure during pregnancy associated with decreased breastfeeding duration
  - Doubling in PFOA associated with 0.5 month (95% CI: 0.3, 0.7) reduction in exclusive breastfeeding duration
- Animal studies show that PFAS can influence breast development and lactation hormones

Risk of Quitting Breastfeeding at 3 Months by Prenatal PFOA

4th vs. 1st quartile RR=1.8, 95% CI: 1.2, 2.5

Romano et al., Environ Res, 2016

Median PFOA in Quartile (ng/mL)
PFAS and Breastfeeding

- Important for mother and infant
- Weanlings dilemma: Does human milk contamination limit the advantage of extended breastfeeding?
- Public health messaging
  - Continue breastfeeding
  - Reduce or minimize exposure
Summary of PFAS Associations with Growth, Adiposity, and Breastfeeding

- High quality epidemiological data suggest that prenatal PFAS exposure associated with
  - Reduced birth weight
  - Increased risk of obesity/overweight and excess adiposity
    - Possibly through alterations in child growth
  - Decreased duration of lactation
Summary of Other Health Effects

- **Neurodevelopment**: “Insufficient” evidence to conclude whether PFAS exposures have adverse effects on child neurodevelopment

- **Immune Function**: NTP monograph has tentative conclusion that PFOA/PFOS are presumed to be immune hazards to humans
Implications of Elevated Water PFOA for Human Health

- Using data from Romano et al. 2016 and Hoffman et al. 2011
- Assuming only water exposure, increased risk of quitting breastfeeding at or below current health advisory level

<table>
<thead>
<tr>
<th>Quartile</th>
<th>Serum PFOA (ng/mL)</th>
<th>Water PFOA (ng/L)</th>
<th>RR of Quitting BF at 3M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>3.1</td>
<td>22</td>
<td>Ref</td>
</tr>
<tr>
<td>2nd</td>
<td>4.6</td>
<td>33</td>
<td>1.32</td>
</tr>
<tr>
<td>3rd</td>
<td>6.3</td>
<td>45</td>
<td>1.63</td>
</tr>
<tr>
<td>4th</td>
<td>10</td>
<td>71</td>
<td>1.77</td>
</tr>
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</table>
Acknowledgements

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NIH  National Institute of Environmental Health Sciences

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Cincinnati Children's Hospital Medical Center

UNIVERSITY OF Cincinnati

CDC

SFU

Simon Fraser University  Thinking of the World

BROWN  School of Public Health