Fluid Consumption and Ambient Temperature among Children in the United States: Implications for Water Fluoridation Policy

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Optimal Water Fluoride Concentration (1 ppm F)

- Dean's 21-cities study (1941, 1942)
  - Maximize dental caries prevention
  - Acceptable level of dental fluorosis
- Community Trials of Water Fluoridation
  - Grand Rapids-Muskegon (1945)
  - Newburgh-Kingston (1945)
  - Evanston-Oak Park (1946)

Adjustment of Water Fluoride Concentration

- Recommended concentration range by ambient temperature
  - Arnold (1943)
  - Galagan and Lamson (1953)
  - Galagan et al (1957)
  - Galagan and Vermillion (1957)
  - US Public Health Service (1962)

Ambient Temperature and Fluid Intake

Galagan DJ et al. (1957)

- Antioch, CA (n=316), Brentwood, CA (n=139)
- 0-10 year-old children
- 5-day fluid intake measurement
  - Drinking water, formula preparations/reconstitution
  - Soup and other water-based beverages
  - Carbonated beverages, juices, and milk
  - **Water used in cooking was not recorded
- 5-day mean daily maximum temperature (°F)

Determining Optimum Fluoride Concentrations

Galagan DJ and Vermillion JR (1957)

- From Antioch and Brentwood, CA:
  \[ E \text{ [Water (oz) per body weight (lb)]} = -0.038 + 0.0062 \text{ temperature (°F) } \]
  “The validity of this equation should perhaps be checked … in other areas of the country, …”

- From known optimal F levels and temperature:
  \[ \text{Parts per million Fluoride} = 0.34 / E \]

Adjustment of Water Fluoride Concentration – USPHS 1962

<table>
<thead>
<tr>
<th>Annual Average of Maximum Daily Temperature (°F)</th>
<th>Recommended optimum fluoride concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50.0 – 53.7</td>
<td>1.2</td>
</tr>
<tr>
<td>53.8 – 58.3</td>
<td>1.1</td>
</tr>
<tr>
<td>58.4 – 63.8</td>
<td>1.0</td>
</tr>
<tr>
<td>63.9 – 70.6</td>
<td>0.9</td>
</tr>
<tr>
<td>70.7 – 79.2</td>
<td>0.8</td>
</tr>
<tr>
<td>79.3 – 90.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>

* Based on temperature data obtained for a minimum of 5 years.
Research Question

- Since these studies were conducted, social and technological changes have affected people’s way of living with an effect on fluid consumption:
  - Air conditioning & central heating
  - Transportation
  - Exercise & outdoor activities

Q: Is fluid (and water) consumption still related to ambient temperature?

Changes in the Pattern of Fluid Intake

Heller et al. 1998; 1999; Sohn et al. 2001; 2009

- Increase of carbonated beverages and juices
- Increase of factory-processed food
- Decrease of water and milk
- Other factors to consider
  - Bottled water
  - Home water conditioning/filtering systems

Other Factors Supporting a Revisiting of Current F Recommendations

- Decrease in dental caries in permanent teeth
- Increase in enamel fluorosis
- Higher fluoride intake
  - Multiple and diverse fluoride sources
  - Changing patterns of fluid intake
  - Beverages manufactured with fluoridated water
- Changes in living condition
- Global warming!??
**Fluid Consumption and Local Climate**

**Mean Total Fluid Intake per Body Weight and Mean Daily Maximum Temperature (NHANES III, 1988-94)**

\[ y = 0.13x + 74.3 \]  
\( p=0.37, R^2=0.001 \)

**Mean Plain Water Intake per Body Weight and Mean Daily Maximum Temperature (NHANES III, 1988-94)**

\[ y = 0.1x + 19.7 \]  
\( p=0.17, R^2=0.001 \)

**Amount of fluid intake and local climate**

Table 4. Multiple regression models of fluid intake per body weight among children aged 1-10 years in NHANES III (1988-1994). (n=3,250)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total Fluid Intake (ml/kg/day)</th>
<th>Plain Water Intake (ml/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \beta )</td>
<td>S.E.</td>
</tr>
<tr>
<td>Age</td>
<td>-6.66</td>
<td>0.35</td>
</tr>
<tr>
<td>Male</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Female</td>
<td>-4.73</td>
<td>1.16</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black</td>
<td>4.28</td>
<td>2.92</td>
</tr>
<tr>
<td>Mexican-American</td>
<td>3.48</td>
<td>2.08</td>
</tr>
<tr>
<td>Others</td>
<td>5.08</td>
<td>3.18</td>
</tr>
<tr>
<td>SES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Middle</td>
<td>-3.06</td>
<td>2.77</td>
</tr>
<tr>
<td>High</td>
<td>-3.18</td>
<td>2.77</td>
</tr>
<tr>
<td>Maximum daily temperature</td>
<td>0.03</td>
<td>0.13</td>
</tr>
<tr>
<td>R-square</td>
<td>0.26</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Limitation: NHANES III**

- 24-hour dietary recall interview
- High Intrai individual variation
- Use of proxy respondents
- Tendency to underestimate consumption
- Biased by season and region
- Limited calendar schedule for MEC visits (Inability to compare region and season variables)
- Absence of extreme temperatures (Truncated temperature range (53.4 - 89.3 °F))
- Limited release of location and time information
- Loss of samples - generalizability, bias
- Use of 30-year mean temperature data for the month

**Overview**

- **Previous analysis (Sohn et al.)** 2007-2008 analysis
  - Fluid intake data
    - NHANES III 1988-1994
  - Public release datasets
    - SANs 1, No 14 (1997) - Home interview, MEC Examination, Dietary Interview
    - SANs 1, No 24 (1998) - Additional dietary data, Vitamin & Medicine data
  - True strata and true PSU, but only largest 35 counties in sample identified

- **Fluid intake data**
  - NHANES III 1999-2004
  - Public release data sets:
    - Demographic, dietary recall
  - Restricted data sets:
    - True strata, true PSU, and true weights
  - Public release data masks true geographic, public release weights based on masked geography

- **Climate data**
  - NOAA NWS temperature
    - Free, public data
    - US National Climatic Data Center (Internet)
    - 30-year normals
  - Assigned PSU/county temperature from a nearby municipal building or airport

- **Climate data**
  - NOAA NWS temperature
    - Free data, via interagency agreement
    - US National Climatic Data Center
    - Actual maximum daily temperature
    - Average of stations in county

**CDC Fluoride Expert Panel**

Brian Burt, Jay Kumar, Steve Levy, Jane McGinley, Howard Pollick, Gary Rozier, John Stamm & Gary Whitford

**Consistency of fluid intake analysis between NHANES III (1988-94) and NHANES 1999-2004**
24-hour Dietary Recall Data

1988-1994
- 24-hour dietary recall interview
- Proxy respondents
- English & Spanish
- Validation by an interviewer - reliable answers
- Use USDA nutrient database and food code
- Dietary data files
  - Total Nutrient Intake
  - Individual Foods File
- Public release data sets

1999-2004
- 24-hour dietary recall interview
  - Same as 1988-1994 except
  - USDA CSFII merged with NHANES
- Protocol changes:
  - Initial 24-hr recall
  - This analysis used only 1st day MEC-collected recall
- Dietary data files
  - Total Nutrient Intake
  - Individual Foods File
- Public release data sets

Classification of fluid sources

1988-1994
- Sohn et al 1988-1994
  - 1) Plain water (tap/spring)
  - 2) Coffee & tea
  - 3) Carbonated drinks
  - 4) Juice
  - 5) Milk
  - 6) Moisture from other food & beverages

1999-2004
- 1) Plain water (tap/spring/bottle)
  - Water based/added
  - 4) Juice
  - 5) Milk
  - 6) Moisture from other foods & beverages

Total fluid intake and ambient temperature

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-6.66 0.35</td>
<td>-8.37 0.78</td>
</tr>
<tr>
<td>Sex</td>
<td>0.00 0.00</td>
<td>0.00 0.00</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td>0.00 0.00</td>
<td>0.00 0.00</td>
</tr>
<tr>
<td>SES Poverty Income Ratio</td>
<td>0.00 0.00</td>
<td>0.00 0.00</td>
</tr>
<tr>
<td>Maximum daily temperature</td>
<td>0.00 0.00</td>
<td>0.00 0.00</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.55 0.19</td>
<td>-1.29 0.28</td>
</tr>
<tr>
<td>Sex</td>
<td>0.00 0.00</td>
<td>0.00 0.00</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td>0.00 0.00</td>
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<td>Maximum daily temperature</td>
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</tr>
</tbody>
</table>

Limitations

Modeling approach

- R-square low, really low for plain water
- Distribution of respondents still biased by month and annual temperature zone
- Temperature assigned at county level
- Census tract level temperature may improve this somewhat, but temperature not available for all census tracts
Conclusions

- There is no evidence that fluid consumption is significantly related to local climate in contemporary conditions.
- The national temperature-related guidelines for fluoride concentration in drinking water may be due for re-evaluation.
- Relationship between sociodemographic factors and children’s fluid consumption patterns is not consistent over time.

Future Analysis

- Allows better matching of temperature and other climate data to geography in both cycles
- NHANES may have sufficient data to answer some, but not all, questions important for re-evaluation of criteria for concentration of fluoride in drinking water.

Thank you! Questions?

In Memory of Dr. Herschel S. Horowitz

Fluoride in bottled water & temperature

<table>
<thead>
<tr>
<th>Annual average of maximum daily air temperature (°F) where bottled water is sold at retail</th>
<th>Maximum fluoride concentration (mg/L) allowed in bottled water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No fluoride added to bottled water</td>
</tr>
<tr>
<td>50.0 - 52.0</td>
<td>0.2</td>
</tr>
<tr>
<td>52.1 - 60.0</td>
<td>2.0</td>
</tr>
<tr>
<td>60.1 - 70.0</td>
<td>3.0</td>
</tr>
<tr>
<td>70.1 - 79.0</td>
<td>4.0</td>
</tr>
<tr>
<td>79.1 - 80.0</td>
<td>5.0</td>
</tr>
<tr>
<td>80.1 - 89.0</td>
<td>6.0</td>
</tr>
<tr>
<td>89.1 - 90.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Note: FDA regulations require that fluoride be listed on the label only if the bottler adds fluoride during processing; the bottler is not required to list the fluoride concentration, which might or might not be optimal. FDA does not allow imported bottled water with no added fluoride to contain more than 0.3 mg fluoride, or imported bottled water with added fluoride to contain more than 1.0 mg fluoride.