• Obligate intracellular parasite
  – Can replicate only in a host cell

• Has no independent metabolic capacity
  – Utilize host cell machinery to replicate an autonomously evolving genome and spread to a new host

• Inert particle
  – Genome surrounded by a protective protein layer (capsid)

Table 1. Viruses that are, or have the potential to be, transmitted via food and their site of infection in the human body.

<table>
<thead>
<tr>
<th>Site of Infection</th>
<th>Virus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neural tissue and nervous system</td>
<td>Enterovirus, Norovirus, Poliovirus, Parechovirus, Tick-borne encephalitis virus*</td>
</tr>
<tr>
<td>Respiratory system</td>
<td>HPAI-H5N1, SARS-CoV</td>
</tr>
<tr>
<td>Liver</td>
<td>HEV, HAV, HEV</td>
</tr>
<tr>
<td>Intestinal system</td>
<td>NorV, HRF, Sapovirus, Astrovirus, Adenovirus, Aichi virus</td>
</tr>
</tbody>
</table>

Note: Enteric viruses can also be airborne, bloodborne (including vector-borne) or sexually transmitted.
* While these viruses have the potential to be transmitted via food they were not considered further by the meeting.
Human Enteric Viruses

- Different control strategies required in food preparation compared to bacteria
  - Resistant to chilling, freezing, preservatives, low pH
  - Generally susceptible to adequate cooking temp. (>85°C)
  - Cannot multiply in foods
    - But very low infectious dose required for infection
  - Long survival in the environment
    - Weeks to months in refrigerated and frozen foods and cold waters
- Human feces may contain up to $10^8$ virions/g during infection
  - Primary carrier for transmission

Norovirus Illness

- Incubation period: 12-48 hours
- Acute-onset vomiting and/or diarrhea
  - Watery, non-bloody stools
  - Abdominal cramps, nausea, low-grade fever
- Most recover after 12-72 hours, self-limiting
  - 10-12% seek medical attention; some require hospitalization and fluid therapy
  - More severe illness and death possible in elderly and those with other illnesses
  - Virus shedding could happen for 3 weeks after illness
- Up to 30% of infections are asymptomatic
- Only short-term immunity (<2 years) is gained

Single Known Causes of U.S. Foodborne Outbreaks Reported to National Outbreak Reporting System (NORS), 2009-2012

<table>
<thead>
<tr>
<th>Cause</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norovirus</td>
<td>48%</td>
</tr>
<tr>
<td>Bacteria</td>
<td>46%</td>
</tr>
<tr>
<td>Chemicals/Toxins</td>
<td>6%</td>
</tr>
<tr>
<td>Parasites</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>1%</td>
</tr>
</tbody>
</table>

Norovirus

- First discovered in fecal samples after outbreak in Norwalk, OH (1968)
- Originally named “Norwalk virus
- Transmission via human feces and vomit
  - 30 million virions shed in one vomiting episode
- Infectious dose very low ~18 virions
- Viron size ~27 nm
Norovirus and Hepatitis A virus - significant burden of foodborne illness globally and in the European region

Norovirus - most common cause of foodborne illness in the European region
- close to 15 million cases each year, causing more than 400 deaths

Hepatitis A - ~100,000 cases each year, causing ~200 deaths

The burden of Norovirus disease in children in the European Union

Frank Kowalszk, MD,* Margarita Riera-Montes, MD, MSc,† Thomas Verstraeten, MD, MSc,† and Fred Zepp, MD*

The Pediatric Infectious Disease Journal • Volume 34, Number 3, March 2015 (www.pidj.com)

Data from 12 studies were included … NoV infection may cause up to 5.7 million illnesses in the community, 800,000 medical visits, 53,000 hospitalizations and 102 deaths every year in children younger than 5 years in the EU.

The burden of NoV disease in children in the EU is substantial, and will grow in relative importance as rotavirus (RV) vaccines are rolled out in the EU. This burden of disease is comparable with the burden of RV disease in the EU before RV vaccine introduction. More country specific studies are needed to better assess this burden and guide the potential introduction of a vaccine against NoV at the national level.
**Annual Burden of Norovirus Disease in the United States**

- 570 - 800 Deaths
- 56,000 - 71,000 Hospitalizations
- 414,000 Emergency Department Visits
- 1.7 – 1.9 million Outpatient Visits
- 19 - 21 million Cases (≈5 episodes in avg person’s lifetime)

Hall et al., 2013

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**Contribution of Viruses to Global Burden of Foodborne Disease**

<table>
<thead>
<tr>
<th>Diseases/Infections</th>
<th>Foodborne Illness (millions)</th>
<th>Percentage of Total Illnesses</th>
<th>Foodborne DALYs (millions)</th>
<th>Percentage of Total DALYs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Foodborne</td>
<td>600</td>
<td>92%</td>
<td>33</td>
<td>54%</td>
</tr>
<tr>
<td>Diarrhoeal</td>
<td>550</td>
<td>92%</td>
<td>18</td>
<td>54%</td>
</tr>
<tr>
<td>Norovirus</td>
<td>120</td>
<td>20%</td>
<td>2.5</td>
<td>7.6%</td>
</tr>
<tr>
<td>Hepatitis A Virus</td>
<td>12</td>
<td>2%</td>
<td>1.4</td>
<td>4.2%</td>
</tr>
</tbody>
</table>


---

**Workers and Foods Implicated**

- **520 (52%)** foodborne norovirus outbreaks reported with factors contributing to contamination
  - Infectious food worker implicated as source in 70%
    - Bare-hand contact with ready-to-eat foods identified in 54%
  - Specific food item implicated in **324 (32%)** foodborne norovirus outbreaks
    - 92% implicated foods contaminated during final preparation
    - 75% were foods eaten raw
    - Single food category identified in only 21%
      - Vegetable row crops (30%), fruits (21%), mollusks (19%)

Hall et al. 2014 MMWR
Intervention/Mitigation Strategies

- Thermal/Heat – Cooking and Pasteurization
- High Pressure Processing
- Pulsed Light including UV
- High Powered Ultrasound
- Non-thermal Plasma
- Irradiation
- Freezing
- Drying

High Pressure Processing for Food Applications

200 elephants weighing 3000 kg each standing on a piston with a diameter of a CD, create a pressure of 600 MPa, 6000 bar or 90,000 psi

HPP Applications

24 L High Pressure Sterilization Unit Max: 890 MPa @ 131˚C
**Effect of Temperature on MNV-1 Inactivation**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Control</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>4C Media</td>
<td>0</td>
<td>0.9</td>
<td>2.51</td>
<td>4.1</td>
<td>5.6</td>
<td>4.8</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>20C Media</td>
<td>0</td>
<td>-0.12</td>
<td>-0.19</td>
<td>-0.18</td>
<td>0.49</td>
<td>1.89</td>
<td>3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Log reduction of MNV-1 (log PFU/mL)

**High Pressure Processing and Viruses**

- **Poliovirus**
- **Feline calicivirus**
- **Hepatitis A virus**

**Distribution of study subject infection status among oyster treatment groups in a HPP challenge study**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Treatment conditions</th>
<th>HPP-treated oysters</th>
<th>Untreated oysters</th>
<th>No. of subjects infected/total (%) postchallenge</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400 MPa, 25°C, 5 min</td>
<td>3/5 (60)</td>
<td>7/15 (47)</td>
<td></td>
<td>1.0000</td>
</tr>
<tr>
<td>2</td>
<td>600 MPa, 6°C, 5 min</td>
<td>0/10 (0)</td>
<td>7/15 (47)</td>
<td></td>
<td>0.0202</td>
</tr>
<tr>
<td>3</td>
<td>400 MPa, 6°C, 5 min</td>
<td>3/14 (21)</td>
<td>7/15 (47)</td>
<td></td>
<td>0.2451</td>
</tr>
</tbody>
</table>

Leon et al., 2011, AEM (77) 5476-5482

**HPP Inactivation of Surrogates**

- **AiV**
- **FCV**
- **MNV**
- **PEC**
- **TuV**

In collaboration with Jan Vinje et al at CDC, Cromeans et al., 2015
Pulsed Light

Pulsed light is a food processing method that involves the use of intense and short duration pulses of a broad spectrum.

Xenon Steripulse XL-3000TM pulsed light system
1.271/cm², 3 pulses/second

Pulsed Light on Stainless Steel

MNV-1 Inactivation and Temperature on Stainless Steel at Distance of 10.8 cm

R² = 0.9791

Effect of PL (100 pulses/s) on inactivation of MNV-1 on Strawberry

- Broad spectrum (100-1000 nm) includes 54%, 26% and 20% of the energy at UV light, visible, and infrared region, respectively.
- Inactivation of pathogenic and spoilage microorganisms on foods and packages (surface)
Mechanisms of Inactivation

- Photochemical or photothermal reactions
- UV plays a critical role in microbial inactivation

Proportion of food handlers at risk of norovirus infection according to the handwashing compliance level when a norovirus carrier is presented in the system (20 simulations).

Result: 100%, 50%, 20.8%, and 7.9% of population are at risk of norovirus infection when 2%, 10%, 18%, and 20% of the food handlers wash their hands before changing task respectively.

Li and Schaffner, 2009

Importance of Handwashing

Proportion of food handlers at risk of norovirus infection according to the handwashing compliance level when a norovirus carrier is presented in the system (20 simulations).

Result: 100%, 50%, 20.8%, and 7.9% of population are at risk of norovirus infection when 2%, 10%, 18%, and 20% of the food handlers wash their hands before changing task respectively.

Li and Schaffner, 2009

Take Home Message: How to Control Foodborne Viruses?

- Noroviruses – the ultimate pathogen? Smarter than what we think.
- Stop contamination at the source
  - Shellfish and fresh produce GAP
  - Harvest shellfish from clean waters; 1 week cessation after rainfall
- Employ effective validated treatments to food where possible
- Good personal hygiene
  - Give ill workers paid sick leave
  - Wash hands
    - With soap and water
    - Even during produce harvesting
Acknowledgements

“A virus is a piece of bad news wrapped in a protein”

Prof. Peter Medawar
Nobel Prize Winner, 1960

Alvin Lee
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