A Brave New World: The Challenges and Promises of Modern Food Safety

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Outline

❖ Challenges:

- Food Safety in a Changing World.

- Burden/ Avoidable Tragedies.

- Resistance.

❖ Adaptations:

- Biofilms.

- VBNCs.

❖ Beyond the Great Plate Anomaly:

- The Age of Genomics.
Food Production/ Service Environment

- A complex and dynamic environment (raw material, storage, prep units, cooking, personnel, traffic).

- Diverse and specialized services (restaurants, school and hospital cafeterias, catering operations, and many other formats). **Globalization!**

- Increasing demand in modern society: High quality, fast service, low prices.

- Increasing competition in the industry
Food Safety and the Food Industry

- Contamination occurs when food is mishandled, including improper cooking and cooling of foods. Contamination may be hard to detect, because the food may not look, taste, or smell differently.

- In addition to public health risks, foodservices/brands associated with an outbreak experience loss of clientele and bad publicity, leading to devastating financial losses.

- Protecting food from contamination and cross-contamination is a priority.
The Burden of Foodborne Illnesses

- Foodborne and waterborne diarrheal diseases cause an estimated **2 million deaths annually**.

- Contaminated food containing harmful organisms or chemicals can cause more than **200 diseases that range from diarrhea to cancer**.

- Approximately **48 million individuals** in the USA (1 in 6 Americans) get sick from food poisoning, while **128,000 are hospitalized** and **3,000 die** each year.

- Foodborne illness are estimated to cost **$77.7 billion in** economic burden in the United States annually.
The Burden of Foodborne Illnesses

- Food poisoning cause a wide range of symptoms, which can develop quickly (thirty minutes in some cases) and last up to several days.

- Symptoms may include diarrhea, meningitis, kidney failure, chronic arthritis, brain and nerve damage, and death.

- Pregnant women, the elderly, children, and patients with chronic illnesses are especially susceptible to food poisoning.

- In the USA, 31 major pathogens are responsible for 9.4 million episodes of foodborne illness, about 56,000 hospitalizations, and 1,300 deaths yearly.
# The Burden of Foodborne Illnesses

*Top five pathogens* contributing to acquired foodborne illnesses (USA)

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Estimated number of illnesses</th>
<th>90% credible interval</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Norovirus</strong></td>
<td>5,461,731</td>
<td>3,227,078–8,309,480</td>
<td>58</td>
</tr>
<tr>
<td><em>Salmonella</em>, nontyphoidal</td>
<td>1,027,561</td>
<td>644,786–1,679,667</td>
<td>11</td>
</tr>
<tr>
<td><em>Clostridium perfringens</em></td>
<td>965,958</td>
<td>192,316–2,483,309</td>
<td>10</td>
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<tr>
<td><em>Campylobacter spp.</em></td>
<td>845,024</td>
<td>337,031–1,611,083</td>
<td>9</td>
</tr>
<tr>
<td><em>Staphylococcus aureus</em></td>
<td>241,148</td>
<td>72,341–529,417</td>
<td>3</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td>91</td>
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When things go bad: Avoidable Tragedies!

20 years after Jack in the Box, foodborne illnesses still an issue

Darin Detwiler, a senior policy coordinator for food safety at STOP Foodborne Illness in Chicago and a graduate lecturer in regulatory affairs of the food industry at Northeastern University in Boston, writes in this op-ed:

I am deeply saddened to read about the deaths this year of two young girls (one in Whatcom County and another in Portland,) both caused by E.coli.

My 16-month-old son, Riley Detwiler, died from E.coli during the 1993 “Jack in the Box” outbreak. He became ill just as the Whatcom County Health Department warned of a child with E. coli at his daycare. The other child ate an undercooked, contaminated hamburger at the Bellingham restaurant. After noticing symptoms, I took Riley to St. Joseph’s Hospital where, after two days, doctors decided to airlift him to Children’s Hospital in Seattle.

Doctors removed most of his intestines, destroyed by foodborne pathogens, and collaborated with experts to make him healthy. I stood every day beside Riley’s little toddler body — dwarfed by wires and tubes. He laid in a coma for weeks until I held him one last time after he died. His poisoning and death made national headlines — even gaining the attention of President Clinton.
The *Listeria* Hysteria!

The National Institute for Communicable Diseases (NICD) is asking victims in South Africa to list everything they can remember eating in the past month with the hopes of identifying a source.

164 people have died, 43 percent of which were babies less than a month old.

Since proper cooking temperatures kill *Listeria*, the food source is thought to be a fruit, vegetables or a ready-to-eat food item. Additionally, the possibility of ill-treated irrigation water is a likely culprit of the pathogen.

South Africa is in desperate need for an update to their entire food system, a call for “a dramatic overhaul of our legislation and the entire food safety system.”

For example there were fewer than 2,000 environmental health practitioners responsible for monitoring all food outlets from restaurants to informal vendors; the WHO said that South Africa needs 5,000 of them.
Displaced communities, Refugees and the Disenfranchised

The Guardian

Hundreds at Iraq refugee camp ill from contaminated food

UN says police investigating after 600 who had fled Mosul fighting got food poisoning from meal supplied by UK charity

World Health Organization

Refugees and migrants are more prone to foodborne diseases

When people are on the move and reach geographical areas different from those of their home country, they are more likely to experience disrupted or uncertain supplies of safe food and water, especially under difficult and sometimes desperate circumstances. In addition, basic public services – such as electricity and transport – can break down. In these conditions, people may be more prone to use inedible or contaminated food ingredients, cook food improperly, or eat spoiled food.

Refugees and migrants typically become ill during their journey, especially in overcrowded settlements. Living conditions can lead to unsanitary conditions for obtaining, storing or preparing food, and overcrowding increases the likelihood of outbreaks of food- and waterborne diseases. Examples of such diseases are salmonellosis, shigellosis, campylobacteriosis and norovirus and hepatitis A infections.

Know the food you eat

When people do not know a new environment but forage for food, they can fall victim to toxic plants that look similar to edible species in their own countries, as happened in Germany when refugees ate poisonous mushrooms. While some toxic fungi just cause vomiting and diarrhoea, others can cause hallucinations, kidney and liver damage and even death.
Rising Tide of AMR!

“In Syria, part of the problem is rooted in the country’s lax attitude toward medications. As in much of the Middle East, antibiotics have long been available without a prescription and are often seen as cure-alls with no side effects. For years, doctors doled them out for everything from headaches to common colds. Farmers in isolated areas self-medicated. Pharmacists who knew the risks prescribed them anyway, fearing their customers would go elsewhere. And with dozens of pharmaceutical factories churning out products across the country, antibiotics became available at low cost to pretty much everyone.” TANYA HABJOUQA/NOOR FOR NEWSWEEK
The Burden of Antimicrobial Resistance (AMR)

Hard to predict. However, based on certain scenarios, it is estimated that:

- “300 million people are expected to die prematurely because of drug resistance over the next 35 years (by 2050) and the world’s GDP will be 2 to 3.5% lower than it otherwise would be in 2050.

- This means that between now (2014) and 2050 the world can expect to lose between 60 and 100 trillion USD worth of economic output if antimicrobial drug resistance is not tackled. This is equivalent to the loss of around one year’s total global output over the period, and will create significant and widespread human suffering.

- Furthermore, in the nearer term we expect the world’s GDP to be 0.5% smaller by 2020 and 1.4% smaller by 2030 with more than 100 million people having died prematurely.”

Campylobacter: Antibiotic Resistance

- In Germany, 42% of chicken-associated C. jejuni were resistant to ciprofloxacin.

- In Poland, 47.9% of the Campylobacter strains isolated from poultry were resistant to ciprofloxacin in the mid-1990s (1994 – 6) in comparison to 90.2% approximately a decade later (2005 – 8).

- Similarly, in the same time interval, erythromycin-resistant Campylobacter associated with poultry increased from 49.3 to 88.9%.

- In the United States, a comparison between 2001 and 2010 showed that the detection rate of ciprofloxacin and erythromycin-resistant C. jejuni on chicken carcasses at slaughter increased from 20.3 to 23.1% and from 0 to 10%, respectively.
Factors Contributing to Changing Trends in Foodborne Disease

- **Rapid population growth and a demographic shift towards an ageing population.**

- **An increasingly global market in vegetables, fruit, meat, ethnic foods, and even farm animals, some of which originate from countries without appropriate microbiological safety procedures.**

- **Improved transport logistics and conditions, which enable agents to survive on food products and reach the consumer in a viable form.**

- **An increasingly transient human population carrying its intestinal flora worldwide.**

- **Changing eating habits, such as the consumption of raw or lightly cooked food, and the demand for exotic foods, such as bush meats.**

- **The shift from low- to high-protein foods as nations develop economically with a concomitant and global greater dependency on meat and fish products.**

Newell et al. 2010

Factors Contributing to Changing Trends in Foodborne Disease

- Higher proportions of immunologically compromised individuals either as a consequence of changing demographics producing an increasingly elderly population or the generation of highly susceptible groups with immunosuppressive diseases or treatments.

- **Changing farming practices**, for example intensification to produce cheaper food or a shift to free-range/organic animal production to respond to consumer welfare concerns.

- **The increasing intrusion of man on native wildlife habitats.**

- **Climate change**, for example bringing novel vectors into temperate regions or temperature-associated changes in contamination levels.

[Newell et al. 2010](https://climate.nasa.gov/effects/)
Microbial Adaptations: Biofilms

- Biofilms are an aggregation of microorganism attached to and growing on a surface. They are usually formed in response to an inhospitable environment/ stress as a survival strategy.

- It is now recognized that biofilms are a frequent source for infections. Around 80% of persistent bacterial infections in the United States were found to be associated with biofilms.

- Biofilms can render their inhabitants more resistant to disinfection.

- Biofilm are more resistant to antimicrobial agents than planktonic bacteria, as they have a barrier which prevents or lessens the contact with antimicrobial agents.

- Therefore, biofilms have become problematic in human medicine and in a wide range of food industries, including brewing, seafood processing, dairy processing, poultry processing, and meat processing.


Srey et al., 2013
Biofilm formation

- Biofilms can be formed of **single species or multiple species**.
- Biofilm formation mechanisms are complex and not completely understood. However, quorum sensing is believed to play an important part.
- Biofilm formation is a stepwise and dynamic process consisting of (i) initial attachment, (ii) irreversible attachment, (iii) early development of biofilm architecture, (iv) maturation, and (v) dispersion.
- Biofilms are also a vehicle of **dispersion of bacterial cells**.
- The formation and development of biofilms is affected by many factors, including **specific bacteria strains**, **material surface properties**, and **environmental parameters such as the pH and nutrient levels and temperature**.
Biofilms in Food and on Food Surfaces

Bacterial adhesion to common food-contact materials

<table>
<thead>
<tr>
<th>Material</th>
<th>S. Typhimurium LT2</th>
<th>L. innocua NADC 2841</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE (c,d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>(e,f)</td>
<td>(g,h)</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>(i,j)</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
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</tbody>
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**Biofilms in the Food Industry**

- In natural and industrial water supplies, despite the low nutrients content. The numbers of planktonic cells found are 500 to 50,000 times lower than the number of cells in biofilm.

- *Streptococcus thermophilus* has been found attached to the heat exchangers in milk processing equipment. Biofilm was found on the pasteurized milk effluent side and on the side where the raw milk enters respectively.

- *Bacillus cereus* spores have also been found in milk, these cause problems because they are hydrophobic and are therefore drawn to the surfaces of the pipes in the process equipment. The milk pasteurization process is not enough to eliminate the spores, and only kill the vegetative cells. *Bacillus cereus* spores attach to the stainless steel surfaces.

- *Listeria monocytogenes* has been detected in drains, floors and process equipment.

- The other common sources involved in biofilm accumulation are the floors, waste water pipes, bends in pipes, rubber seals, conveyor belts, stainless steel etc.

- The investigated sites of biofilm formation in an ice cream plant showed that most of the biofilm formations were seen on the conveyor belt of a packaging machine 8 h after the beginning of the production.
Food for thought!

SANITIZER

Nearly 30% of food processing drains tested positive for listeria
source: USDA
Microbial Adaptations: VBNCs

Survival and Viability of Nonculturable *Escherichia coli* and *Vibrio cholerae* in the Estuarine and Marine Environment

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Abstract. Plating methods for estimating survival of indicator organisms, such as *Escherichia coli*, and water-borne pathogens including *Vibrio cholerae*, have severe limitations when used to estimate viable populations of these organisms in the aquatic environment. By combining the methods of immunofluorescent microscopy, acridine orange direct counting, and direct viable counting, with culture methods such as indirect enumeration by most probable number (MPN) estimation and direct plating, it was shown that both *E. coli* and *V. cholerae* undergo a “nonrecoverable” stage of existence, but remain viable. Following 2-week incubations in saltwater (5–25% NaCl) microcosms, total counts, measured by direct microscopic examination of fluorescent antibody and acridine orange stained cells, remained unchanged, whereas MPN estimates and plate counts exhibited rapid decline. Results of direct viable counting, a procedure permitting estimate of substrate-responsive viable cells by microscopic examination, revealed that a significant proportion of the nonculturable cells were, indeed, viable. Thus, survival of pathogens in the aquatic environment must be re-assessed. The “die-off” or “decay” concept may not be completely valid. Furthermore, the usefulness of the coliform and fecal coliform indices for evaluating water quality for public health purposes may be seriously compromised, in the light of the finding reported here.
VBNCs

Bacterial colonies growing on an agar plate = Culturing

No growth on an agar plate = VBNC

VBNC formation
Stress/other environmental signals

Resuscitation
Back to cuturable form
VBNCs (*Campylobacter; Vibrio*)
The cells that form a colony on specific nutrient media are the culturable cells.

Viable means metabolically or physiologically active.

“VBNC can be defined as a metabolically active bacterial cell that crossed a threshold, for known or unknown reasons, and became unable to multiply in or on a medium normally supporting its growth.”

Therefore, VBNCs maintain a detectable but reduced metabolism (e.g., decrease in respiration, nutrient transportation, and synthesis of macromolecules), relatively high ATP levels, and aspects of cellular integrity such as intact chromosome content and cell membrane.

Additional VBNC characteristics also occasionally include changes to cell morphology such as “rounding up” and reduction in the size of the cells, which is thought to maximize the surface area available for nutrient uptake while minimizing cell mass.

VBNC have apparent capacity to regain culturability in vivo, can respond to external stimulus as shown by specific gene expression; retain plasmids; have increased antibiotic resistance due to lower metabolic activity, exhibit changes in outer-membrane protein profile and continuous gene expression.
Most of the bacteria that enter VBNC state are gram-negative species.

The following list includes some of the pathogenic bacteria that can enter the VBNC state: *Aeromonas hydrophila*, *Agrobacterium tumefaciens*, *Burkholderia cepacia*, *Campylobacter jejuni*, *Enterobacter aerogenes*, *Enterobacter cloacae*, *Enterococcus faecalis*, *Escherichia coli* (including EHEC), *Helicobacter pylori*, *Klebsiella pneumoniae*, *Legionella pneumophila*, *Listeria monocytogenes*, *Mycobacterium tuberculosis*, *Pseudomonas aeruginosa*, *Salmonella typhi*, *Salmonella typhimurium*, *Shigella dysenteriae*, *Shigella flexneri*, *Shigella sonnei*, *Streptococcus faecalis*, *Vibrio alginolyticus*, *Vibrio cholerae*, *Vibrio harveyi*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus* (types 1 and 2).

Food and environmental and clinical samples no longer can be considered free from pathogens if culturing yields negative results.

It is possible that in many cases, the infections are incorrectly attributed to viruses since no bacteria were detected.

Controversy: VBNC state were thought to be unable to induce infection/disease despite retaining their virulent properties.

However, when VBNC pathogens pass through a host animal, resuscitation and resumption of metabolic activity have led to infections and diseases.

Fakruddin et al, 2013
Kassem et al., 2013
The presence of VBNC bacteria in food has been documented.

Food and its surrounding environment are a complex system, in which physiochemical characteristics (pH and chemical composition) and environmental factors (storage temperature and time, decontamination treatments, and packaging under modified atmosphere) act simultaneously on bacteria and might lead to the VNBC state.

For example, it has been demonstrated that refrigerated pasteurized grapefruit juice induced the VNBC state in *E. coli* O157:H7 and *S. typhimurium* within 24 hours of incubation.

In pasteurized milk which has undergone thermal treatment, contaminating bacteria such as *E. coli* and *Pseudomonas putida* enter into the VNBC state and retain transcription and translation functions.

*C. jejuni* VBNC can adhere to the skin of chicken carcasses.

Several foodborne outbreaks have been reported in Japan, where pathogens such as *Salmonella enterica subsp. enterica* and *E. coli* O157 in the VNBC state were responsible for the outbreaks.

The VNBC is also critical in determining shelf life and microbial stability of food and beverages. For example, acetic acid and lactic acid bacteria entered the VNBC state in wine as a consequence of lack of oxygen and presence of sulphites.
Beyond the Great Plate Anomaly: The Age of Genomics

- Only a small percentage of soil bacteria (1%) are culturable, even when using a set of media (Bakken, 1997).
- Higher estimates have been reported.

- A single gram of soil can harbor up to $10^{10}$ bacterial cells and an estimated species diversity of between $4 \cdot 10^3$ (Torsvik et al., 1990) to $5 \cdot 10^4$ species (Roesch et al., 2007).
Listeria in Ice Cream

Listeria and Blue Bell Ice Cream
Contaminated production facilities and illnesses linked to Blue Bell Creameries

CDC recommends that people not eat, serve, or sell any recalled Blue Bell brand products. This complicated investigation of a listeriosis outbreak involved serious illnesses from 2010 through 2015 linked to two Blue Bell production facilities.

Arizona
- 1 case linked to ice cream made in Oklahoma facility

Kansas
- 5 cases in one hospital linked to ice cream made in Texas facility, resulting in 3 deaths

Oklahoma
- 1 case linked to ice cream made in Oklahoma facility
- Listeria found in ice cream products and in Oklahoma facility where they were made

Texas
- 3 cases in separate hospitals linked to ice cream made in Oklahoma facility
- Listeria found in ice cream products made in Texas facility

Alabama
- Listeria found in Alabama facility
- No cases linked to Alabama facility

Magnified 41,250X Listeria monocytogenes (CDC PHIL #2287).

Learn more: www.cdc.gov/listeria/bluebell
WGS provides much greater strain discrimination than other methods for typing foodborne bacterial pathogens. In addition, it provides an all-in-one test in the sense that information usually obtained from other typing methods (including serotyping, molecular subtyping and resistance profiling) can be extracted in silico from the sequence data. WGS-derived phylogenetic analysis improves cluster resolution and is an invaluable tool in epidemiological investigations. Retrospective studies have demonstrated the utility of WGS for detection of FBD outbreaks, case definitions and case ascertainment. Recently, a number of national public health bodies have used WGS for real-time surveillance of foodborne bacterial pathogens.
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- NFSC.
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Thank You!