Emerging Microbiological Food Safety Issues Related to Meat

Michael P. Doyle and Marilyn C. Erickson
Emerging Microbiological Food Safety Issues Related to Meat

- Avian Influenza Virus
- Antibiotic Resistance of Meatborne Pathogens
- Food Attribution
  - Microbial Source Tracking
  - Surveillance of Foodborne Pathogens
  - Microbiological Risk Assessment
- Sensitive Populations at Increased Risk of Meatborne Microbial Infections
- Continuing Microbiological Food Safety Issues
Avian Influenza Virus

- Small RNA virus
- Surface spikes – hemagglutinin & neuraminidase proteins
- 16 hemagglutinin and 9 neuraminidase subtypes – Ex. H5N1, H9N2, H7N7
**Asian H5N1**

- Hong Kong: 1997, 2001-3 (H5N1)
- S. Korea: 2003-4 (H5N1)
- Vietnam: 2004-6 (H5N1)
- Japan: 2004 (H5N1)
- Thailand: 2004-6 (H5N1)
- Cambodia: 2004-6 (H5N1)
- Laos: 2004-6 (H5N1)
- Taiwan: 2003 & 5 (H5N1)
- Indonesia: 2003-6 (H5N1)
- China: 1996-2006 (H5N1)
- Malaysia: 2004 (H5N1)
- Russia, Mongolia, Kazakhstan: 2005 (H5N1)
- Turkey, Romania, Croatia, Ukraine, Cyprus: 2005-6 (H5N1)

**H5N1 HPAI**

- Total dead or culled: 100-200m
- Endemic in village poultry and domestic ducks

New Outbreaks: Nigeria, Egypt, France, Germany, Sweden, Slovenia, Iran, Iraq, Azerbaijan, Bulgaria, Greece, Austria

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- Endemic in village poultry and domestic ducks

New Outbreaks: Nigeria, Egypt, France, Germany, Sweden, Slovenia, Iran, Iraq, Azerbaijan, Bulgaria, Greece, Austria

**World**

A map shows countries affected by the H5N1 virus, including countries such as Hong Kong, S. Korea, Vietnam, Japan, Thailand, Cambodia, Laos, Taiwan, Indonesia, China, Malaysia, Russia, Mongolia, Kazakhstan, Turkey, Romania, Croatia, Ukraine, and Cyprus. The map highlights the spread of the virus from 1996 to 2006.
Avian Influenza

- Viral disease causes sickness or death in poultry but not typically in human (228 cases, 130 deaths; June 20, 2006, but likely millions exposed)
- Domestic poultry can be infected by one or two types of AI viruses:
  - Low Pathogenic AI viruses (Most strains)
    - Generally causes mild or no signs of illness in infected poultry
      - Ruffled feathers, respiratory problems, diarrhea, drop in egg production, increase in mortality
  - High Pathogenic AI viruses
    - Spread quickly and may kill poultry in flock within 72 hours
      - LPAI can mutate to HPAI
Highly Pathogenic Avian Influenza Virus Is Not Easily Spread Among Humans

- Anatomical difference in cells of most human respiratory tracts compared with cells of poultry respiratory tract
  - Deep cells within human respiratory system have key surface receptor for AIV to enter cell
    - AIV must enter cell to multiply and cause disease
  - For respiratory viruses to be transmitted efficiently, they must multiply in upper respiratory tract so they can spread by coughing and sneezing

Reasons for Concern About HPAI H5N1 Virus

- Threatens domestic poultry worldwide, especially chickens
  ▲ Could have serious economic ramifications

- On rare occasions has passed from poultry to humans and caused serious illness and death
  ▲ 130 deaths (June 20, 2006), mostly in Asia

- May change (mutate) into a form that is highly infectious in humans and spread easily from person to person (Pandemic)
**Can AI virus be present in poultry meat?**

### LPAIV & HPAIV in Chickens

<table>
<thead>
<tr>
<th>Virus</th>
<th>Respiratory Tract</th>
<th>GI Tract</th>
<th>Blood</th>
<th>Bone</th>
<th>Meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>H7N2/99 LPAI</td>
<td>++ 1-5d</td>
<td>+ 5d</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H7N2/02 LPAI</td>
<td>+++ 1-7d</td>
<td>++ 2-7d</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H5N2 HPAI</td>
<td>++++ 1-5d</td>
<td>++++ 1-5d</td>
<td>++++ 1-5d</td>
<td>++++ 1-5d</td>
<td>++++ 1-5d</td>
</tr>
<tr>
<td>H5N1 HPAI</td>
<td>ND&lt;sup&gt;a&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>++++ 1-2d</td>
</tr>
</tbody>
</table>

<sup>a</sup>ND, not determined

Demonstration of H5N1 in Poultry Meat

- Experimentally infected with bird isolates (2003-5 S. Korea, Thailand, Mongolia and Indonesian) and human isolates (2004-5 Indonesia, Vietnam & Thailand):
  - Chickens
  - Japanese Quail
  - Geese

- Natural infections:
  - Raw frozen duck meat, 2001 and 2003

Can cooking kill avian influenza viruses in poultry meat?

- Cooking to 70°C (158°F) internal temperature will kill HPAI virus

Consumer Guidelines for the Safe Cooking of Poultry Products

- Consumers should cook poultry to a minimum internal product endpoint temperature of $165^\circ\text{F}$ for microbiological safety, including Avian influenza virus
  ▲ This temperature will kill *Salmonella*, the most heat resistant pathogen of public health concern on raw poultry

National Advisory Committee on Microbiology Criteria for Foods, March 24, 2006
Summary

- The Asian H5N1 HPAI virus has spread into northern and western Asia, and Europe and Africa, with evidence of involvement of migratory birds, but poultry still are the primary vehicle of transmitting the virus.

- Considering likely widespread exposure, human infections are uncommon and from direct contact with sick or dead poultry.

- HPAI virus can be present in poultry meat and blood but epidemiologic evidence indicates not a food safety issue.

- Firewalls are in place to prevent HPAI virus-infected poultry from entering USA food supply.

- Proper handling and cooking (165°F) of poultry further ensures safety from HPAI virus.
Antibiotic-Resistant Foodborne Pathogens
Public Health Issues Associated with Antibiotic-Resistant Foodborne Pathogens

- May be failure of drug treatment by critical antibiotics needed for human therapy, especially important for systemic infections
- May be increased risk of infection to people taking antimicrobials to which pathogen is resistant
- May be more severe manifestations of illness associated with some drug-resistant pathogens
  - For example, longer duration of illness, and more systemic infections and hospitalizations
- Possible co-selection of virulence traits (e.g., toxin-encoding genes) associated with antimicrobial-resistant microbes
Clinical Importance of Specific Antibiotics

- Ceftriaxone -- drug choice (cephalosporin) for treatment of severe salmonellosis in humans, especially children.
- Ceftiofur -- only cephalosporin approved for systemic use in food animals in the United States.
  - Ceftiofur-resistant microbes exhibit decreased susceptibility for extended-spectrum cephalosporins.
- Erythromycin -- drug of choice for treatment of severe campylobacteriosis.
- Ciprofloxacin -- used for the empirical treatment of gastroenteritis and is recommended for treatment of infections caused by macrolide (erythromycin) resistant campylobacters.
Examples of Antibiotic-Resistant Foodborne Pathogens in the United States

- Multidrug-Resistant Non-Typhi *Salmonella*
  - *Salmonella* Typhimurium DT104 - R-type: ACSSuT
    - Five agents: ampicillin, chloramphenicol, streptomycin, sulfamethoxazole, tetracycline
  - *Salmonella* Newport - R-type: MDR-Amp C
    - Nine agents: ampicillin, chloramphenicol, streptomycin, sulfamethoxazole, tetracycline, amoxicillin-clavulanic acid, cephalothin, cefoxitin, ceftiofur, (and decreased susceptibility to ceftriaxone)
- Ciprofloxacin-resistant *Campylobacter*
Examples of Antibiotic-Resistant Foodborne Pathogens in the United States (Cont’d)

- NOT issue with *E. coli* O157:H7
  - Antibiotic treatment is contraindicated because of potential exacerbation of manifestations of illness (renal failure)
- Vancomycin-resistant *Enterococcus faecium* and *E. faecalis*
  - Largely hospital-acquired infections in intensive care units but food **not** identified as vehicle of transmission in USA
Antibiotic Treatment of *Salmonella* Infection

- Not needed for mild diarrhea
- Used to prevent complications in neonates, immunosuppressed, and persons > 50 years of age
- Life-saving in invasive infections (e.g., meningitis)
- Important antibiotics include amoxicillin, ceftriaxone, ciprofloxacin, trimethoprim-sulfa
Dominant Multidrug-Resistant *Salmonella* from Humans in United States, 2002

- Four multidrug-resistant strains accounted for 8% (169/2009) of non-Typhi *Salmonella* isolates from humans assayed by CDC NARMS
  - S. Typhimurium R-type ACSSuT (21% of all isolates of S. Typhimurium)
  - S. Newport MDR-Amp C (22% of all isolates of S. Newport)
  - S. Typhimurium R-type AKSSuT (6% of all S. Typhimurium)
  - S. Heidelberg R-type ACICfCp (8% of all S. Heidelberg)

Centers for Disease Control and Prevention National Antimicrobial Resistance Monitoring System for Enteric Bacteria, 2002
Trends in percentage of antibiotic-resistant *Salmonella Typhimurium* isolated from human cases, animals and animal products, and retail meats in the United States (NARMS-CDC, 2002; NARMS-FDA, 2002; NARMS-USDA, 2003)

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>None of 14 agents</td>
<td>36</td>
<td>60</td>
<td>35</td>
<td>35</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>ACSSuT</td>
<td>34</td>
<td>21</td>
<td>35</td>
<td>27</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ceftiofur</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>27</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Ampicillin</td>
<td>50</td>
<td>34</td>
<td>61</td>
<td>63</td>
<td>56</td>
<td>18</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>49</td>
<td>32</td>
<td>64</td>
<td>64</td>
<td>46</td>
<td>46</td>
</tr>
<tr>
<td>Trimethoprim-sulfa</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
Trends in percentage of antibiotic-resistant *Salmonella* Newport isolated from human cases, animals and animal products, and retail meats in the United States (NARMS-CDC, 2002; NARMS-FDA, 2002; NARMS-USDA, 2003)

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None of 14 agents</td>
<td>82</td>
<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDR-Amp C</td>
<td>0</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ceftiofur</td>
<td>4</td>
<td>22</td>
<td>75</td>
<td>78</td>
<td>74</td>
<td>62</td>
</tr>
<tr>
<td>Ampicillin</td>
<td>6</td>
<td>24</td>
<td>76</td>
<td>80</td>
<td>74</td>
<td>62</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>8</td>
<td>25</td>
<td>78</td>
<td>83</td>
<td>77</td>
<td>62</td>
</tr>
<tr>
<td>Trimethoprim-sulfa</td>
<td>4</td>
<td>4</td>
<td>19</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
Changes in the incidence of foodborne illness and corresponding changes in prevalence of antibiotic-resistant foodborne pathogens in the U.S. (IFT Expert Panel, 2006)

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Antibiotic-sensitive and Antibiotic-resistant</th>
<th>Antibiotic-resistant only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case rate (per 100,000)</td>
<td>Relative Change</td>
</tr>
<tr>
<td>Salmonella spp.</td>
<td>15.9</td>
<td>14.7</td>
</tr>
<tr>
<td>Salmonella Typhimurium</td>
<td>4.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Salmonella Newport</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Campylobacter spp.</td>
<td>18.7</td>
<td>12.9</td>
</tr>
</tbody>
</table>
Concluding Comments

Putting the Antibiotic Resistance Issue in Livestock in Perspective

- Complex issue for which there is no single solution
- Minimizing the use of antimicrobials in agriculture should be weighed against the likelihood of increasing the level of pathogens in food and in humans
Concluding Comments

Putting the Antibiotic Resistance Issue in Livestock in Perspective (Cont’d)

- Sick animals must be treated for humanitarian reasons
- Prudent use of antibiotics in both human and animal medicine is essential
- Use risk analysis, which includes risk assessment, to avoid unintended consequences
  - Evaluate each antibiotic, foodborne pathogen and animal species combination on an individual basis
Food Attribution

- Capacity to attribute cases of foodborne illness to the food vehicle or other source responsible for the illnesses
- Tools available or under development
  - Microbial source tracking
  - Surveillance
- Food attribution data applied in microbiological risk assessments
Microbial Source Tracking

- Tracing pathogens to their origin
  - Use microbiological, genotypes and phenotypic methods
- Example of MST
  - High coliform counts in various sites of Sedona Creek, Arizona
    - Suspected source was leaking septic tanks
    - MST revealed raccoons responsible for 30 – 35% of coliforms and other animals (skunks, coyotes, elk, horses) contribute 50%
      - Human waste responsible for 16% of coliforms
### Examples of outbreaks of human illness with manure as a suspected source between 1989 and 2000 (Smith & Perdek, 2004)

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Location</th>
<th>Year</th>
<th>Suspected source</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Cryptosporidium parvum</em></td>
<td>Carrollton, GA, USA</td>
<td>1989</td>
<td>Manure runoff</td>
<td>13,000 cases</td>
</tr>
<tr>
<td></td>
<td>Swindon and Oxfordshire, UK</td>
<td>1989</td>
<td>Runoff from farm fields</td>
<td>&gt; 516 cases</td>
</tr>
<tr>
<td></td>
<td>Bradford, UK</td>
<td>1994</td>
<td>Storm runoff from farm fields</td>
<td>125 cases</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157:H7</td>
<td>Cabool, MO, USA</td>
<td>1990</td>
<td>Water line breaks in farm community</td>
<td>243 cases, 4 deaths</td>
</tr>
<tr>
<td></td>
<td>Maine and others, USA</td>
<td>1993</td>
<td>Animal manure spread in apple orchard</td>
<td>Several illnesses</td>
</tr>
<tr>
<td><em>Escherichia coli</em> O157:H7 and <em>Campylobacter</em> spp.</td>
<td>Washington County, NY, USA</td>
<td>1999</td>
<td>Runoff at fairgrounds</td>
<td>116 cases, 2 deaths</td>
</tr>
<tr>
<td></td>
<td>Walkerton, ON, Canada</td>
<td>2000</td>
<td>Runoff from farm fields entering town’s water supply</td>
<td>2300 cases, 6 deaths</td>
</tr>
</tbody>
</table>
Microbial Source Tracking

- Underlying assumption that certain subgroups of bacteria became adapted to a particular host or environment
  ▲ Differentiate bacteria adapted to different hosts
    ♦ Identify specific groups of indicator species such as sorbitol-fermenting bifido bacteria, host-specific viruses
    ♦ Genotype methods such as PFGE subtyping, ribotyping, host-specific molecular markers
    ♦ Phenotypic methods such as phage typing, OMP profiles, antibody reactivity, antibiotic resistance profiles, fatty acid profiles
Surveillance of Foodborne Disease

- Purposes/Intended Uses
  - Estimate burden of foodborne disease and monitor trends
  - Identify priorities and set policy in control and prevention of foodborne diseases
  - Detect, control, prevent foodborne disease outbreaks
  - Identify emerging food safety issues
  - Evaluate efficacy of foodborne disease prevention and control strategies

WHO Consultation. 2001. Global surveillance of foodborne disease: developing a strategy and its interaction with risk analysis
### Selected examples of national and international surveillance systems in public health and food safety programs and their roles

<table>
<thead>
<tr>
<th>Surveillance System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epidemiologic surveillance</strong></td>
<td></td>
</tr>
<tr>
<td>Enter-Net (Europe, Canada, Japan, South Africa, Australia, New Zealand)</td>
<td>Monitors <em>Salmonella</em> and STEC O157 human infections.</td>
</tr>
<tr>
<td>National Animal Health Reporting System (USA)</td>
<td>Monitors clinical disease (OIE List A and B) in livestock, poultry and aquaculture.</td>
</tr>
</tbody>
</table>
### Selected examples of national and international surveillance systems in public health and food safety programs and their roles

<table>
<thead>
<tr>
<th>Surveillance System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laboratory surveillance</strong></td>
<td></td>
</tr>
<tr>
<td><strong>PulseNet (US CDC, USDA, FDA, States)</strong></td>
<td>Participants perform standardized molecular subtyping of foodborne disease-causing bacteria by pulsed-field gel electrophoresis (PFGE). DNA “fingerprints” are submitted electronically to a dynamic database. Databases are on-demand to participants and allow for rapid comparison of PFGE patterns.</td>
</tr>
<tr>
<td><strong>WHO Global Salm-Surv</strong></td>
<td>Surveillance, isolation, serotype identification, and antimicrobial resistance testing of <em>Salmonella</em>, <em>E. coli</em>, and <em>Campylobacter</em></td>
</tr>
<tr>
<td><strong>National Antimicrobial Resistance Monitoring System (NARMS)</strong></td>
<td>Monitors changes in susceptibilities to 17 antimicrobial drugs of zoonotic enteric pathogens from human and animal clinical specimens, from healthy farm animals, from carcasses of food-producing animals at slaughter, and from isolates from samples of retail foods.</td>
</tr>
<tr>
<td><strong>eLEXNET (FDA, 50 states)</strong></td>
<td>A secure, integrated, web-based data exchange system for food safety inspection data, and a repository for analytical methods. Enables multiple agencies to assess risks and analyze trends from stored data.</td>
</tr>
<tr>
<td><strong>Global Environmental Monitoring System (GEMS) (FAO, WHO, UN Environment Program)</strong></td>
<td>Compiles data on food contamination and human exposure from different countries for global synthesis, evaluation, and presentation</td>
</tr>
</tbody>
</table>
## Selected examples of national and international surveillance systems in public health and food safety programs and their roles

<table>
<thead>
<tr>
<th>Surveillance System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Animal surveillance</strong></td>
<td></td>
</tr>
<tr>
<td>ANIMO (European Union)</td>
<td>Computerized tracking system used in the European Union to monitor movements of animals within the EU.</td>
</tr>
<tr>
<td>Australia’s National Livestock Identification Scheme (NLIS)</td>
<td>Uses electronic ear tags or rumen boluses to individually identify and trace cattle.</td>
</tr>
<tr>
<td>Collaboration in Animal Health and Food Safety Epidemiology (CAHFSE) (5 states in USA)</td>
<td>Monitors on-farm and in-plant trends in the prevalence of <em>Salmonella</em>, <em>Campylobacter</em>, <em>E. coli</em>, and <em>Enterococcus</em> spp. In market swine.</td>
</tr>
</tbody>
</table>
Microbial Risk Assessments

- A systematic science-based approach to assemble and analyze data of foodborne pathogen contamination, growth and survival in foods and infectious dose

- MRA assesses the risk of a microbial hazard reaching a host and probability of causing harm

- Greatest value is to develop MRA-based targeted and effective risk management strategies
Selected examples of risk assessments of significance to the poultry and meat industry (USDA, 2001, 2003, 2005a, b, c; US FDA, 2002; WHO, 2002a, b, 2004b)

<table>
<thead>
<tr>
<th>Organization</th>
<th>Year</th>
<th>Pathogen</th>
<th>Target food(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USDA FSIS</td>
<td>2001</td>
<td><em>E. coli</em> O157:H7</td>
<td>Ground beef</td>
</tr>
<tr>
<td>WHO</td>
<td>2002</td>
<td><em>Campylobacter</em> spp.</td>
<td>Broiler chickens</td>
</tr>
<tr>
<td>WHO</td>
<td>2002</td>
<td><em>Salmonella</em> spp.</td>
<td>Eggs and broiler chickens</td>
</tr>
<tr>
<td>US FDA</td>
<td>2002</td>
<td><em>Listeria monocytogenes</em></td>
<td>Ready-to-Eat foods</td>
</tr>
<tr>
<td>USDA FSIS</td>
<td>2003</td>
<td><em>Listeria monocytogenes</em></td>
<td>Deli meats</td>
</tr>
<tr>
<td>WHO</td>
<td>2004</td>
<td><em>Listeria monocytogenes</em></td>
<td>Ready-to-Eat foods</td>
</tr>
<tr>
<td>USDA FSIS</td>
<td>2005</td>
<td><em>Clostridium perfringens</em></td>
<td>Ready-to-Eat meat and poultry products</td>
</tr>
<tr>
<td>USDA FSIS</td>
<td>2005</td>
<td><em>Salmonella</em> Enteritidis</td>
<td>Shell eggs</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Salmonella</em> spp.</td>
<td>Egg products</td>
</tr>
</tbody>
</table>
Microbial Risk Assessments

- Inherently predictive
  - Can estimate impact of food safety interventions
- Example, WHO MRA for *Salmonella* in eggs and broiler chickens
  - Evaluate effect of “test and divert” program for *Salmonella* in eggs
    - Testing shell eggs 3 times per yr for 4 yrs reduced risk of human illness by > 90%
    - Testing once a year for 4 yrs reduced risk by ca. 70%
Sensitive Populations at Increased Risk of Foodborne Microbial Infections

- Major demographic changes in world’s population to occur
  - In 2050, predict 3 times as many elderly than in 2002 and comprise 17% of global population
    - Elderly at increased risk to pathogens
      - Weakened immune systems
      - Decreased protection by vaccines
      - Prolonged stays in hospitals
      - Permanent catheterization
      - Malabsorption of nutrients
      - Problems associated with drug use
      - Renal insufficiency
Sensitive Populations at Increased Risk of Foodborne Microbial Infections

- Immunocompromised population
  - Greater likelihood of infection
  - Greater likelihood of illness if infected
  - More severe or complicated disease if ill
  - Greater likelihood of death
  - Increased potential for illness with a nonpathogen or an opportunistic pathogen
Sensitive Populations at Increased Risk of Foodborne Microbial Infections

- Conditions of immunocompromised that predispose them to foodborne zoonotic infections
  - Age
  - Decreased gastric acidity
  - Inflammatory bowel disease
  - Malignancy
  - Immunosuppressive medications
  - Chronic medical conditions
  - HIV/AIDS
Sensitive Populations at Increased Risk of Foodborne Microbial Infections

- Increases in immunocompromised populations have occurred worldwide
  - HIV/AIDS epidemic
  - Life-prolonging treatment of immunodeficiency diseases
  - Use of chemotherapeutic agents and immunosuppressive drugs in cancer and transplantation patients

- Estimated 3.6% of the U.S. population is immunodeficient
  - 20% include elderly and pregnant women
Other Microbiological Issues of Continuing Concern for the Meat and Poultry Industry

- Bovine spongiform encephalopathy (Mad cow disease)
- *Mycobacterium avium* subsp. *paratuberculosis* (Johne’s disease)
- Toxoplasmosis
- Shigatoxin-producing *E. coli* (STEC)
- *Salmonella*
- *Campylobacter*
- *Listeria monocytogenes*
Concluding Comments

- Development of new and more sophisticated/sensitive/specific methods for studying foodborne pathogens and sensitive hosts
  - Better understanding of origin of foodborne disease agents
  - Discriminate more virulent strains from less harmful microbes
  - Identify highly vulnerable human populations
  - **Tracing outbreak-associated pathogens to their source**
- These advances for public health result in greater challenges for meat and poultry industry in producing microbiologically safe products
Concluding Comments

- Innovative solutions on the horizon
  - Identifying most impactful control strategies for ranking microbial hazards through risk assessments
  - Developing innovative antimicrobial treatments
  - Providing practical on-farm and in-plant interventions
  - Enabling rapid identification of microbial contamination for rapid response