



Microbiological Safety of Food, Particularly for Vulnerable People

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Abstract

Foodborne illness affects about one in six Americans each year. Certain groups of people are particularly susceptible to foodborne illness, these include the very young, the elderly, pregnant women and people whose immune system is suppressed by disease or medication. These groups are most likely to incur infection and to suffer severe consequences. Major foodborne pathogens and foods that are particularly associated with hazards are outlined. Factors leading to outbreaks are described and illustrated with examples of outbreaks. Prevention of transmission of foodborne pathogens involves use in the supply of food of a system based on the Hazard Analysis Critical Control Point System (HACCP) and prerequisite programs, and the selection of lower-risk foods in place of higher-risk foods for vulnerable people.

Keywords

Salmonella, Toxoplasma, Listeria, Campylobacter, Norovirus, HACCP, Low-microbial diet, Neutropenic diet

Abbreviations

HACCP: Hazard Analysis Critical Control Point, STEC: Shiga Toxin-Producing Escherichia coli

Incidence of Foodborne Disease, and Major Foodborne Pathogens

It is estimated that each year one in 6 Americans becomes ill as

a result of consuming contaminated food or beverages [1]. Most of these illnesses are caused by pathogenic microorganisms including bacteria, viruses and parasites. A wide range of pathogens can cause foodborne disease and result in different types of symptom. The annual incidence of foodborne illness caused by 31 foodborne pathogens in the USA was estimated by Scallan et al. [2]; results for major pathogens are shown in table 1. The main causes of deaths were non-typhoidal *Salmonella* (NTS), *Toxoplasma gondii* and *Listeria monocytogenes*. Reports from Canada and Europe show a majority of cases caused by *Campylobacter*, *Clostridium perfringens*, norovirus, non-typhoidal *salmonella* (NTS), and shiga-toxin-producing *Escherichia coli* (STEC), and a high case-fatality due to the parasite *T. gondii* and to *L.monocytogenes* [3]. An assessment was made in the US of loss of quality-adjusted life years (QALY), taking into account long-term sequelae, for 14 foodborne pathogens [4]; results for the five pathogens that contribute 90% of the total QALY loss are shown in table 2. In their list of major foodborne pathogens the FDA includes the following organisms that cause fewer cases of illness but can have very serious consequences, particularly in vulnerable people, *Cryptosporidium*, *Vibrio vulnificus* and in infants *Cronobacteria* [5]. The present paper will discuss the importance and consequences of foodborne infection in vulnerable people and methods to prevent infection, using examples involving the foodborne pathogens responsible, in industrialized countries, for the greatest burden of disease in terms of loss of QALY and number of cases of illness.

Table 1: Estimated annual number of domestically acquired foodborne illnesses, hospitalizations and deaths caused by major foodborne pathogens in the USA. Data from [2].

	Estimated mean number of illnesses	Estimated mean number of hospitalizations	Hospitalization rate (%)	Estimated mean number of deaths	Case-fatality rate (%)
Norovirus	5,461,731	14,663	0.27	149	0.003
<i>Salmonella</i> spp. non-typhoidal	1,027,561	19,336	1.88	378	0.037
<i>Clostridium perfringens</i>	965,958	438	0.04	26	0.003
<i>Campylobacter</i> spp	845,024	8,463	1.00	76	0.009
<i>Staphylococcus aureus</i>	241,148	1,064	0.44	6	0.002
<i>E.coli</i> (STEC) 0157 & non-O157	175,905	2,409	1.37	20	0.01
<i>Shigella</i> spp	131,254	1,456	1.11	10	0.008
<i>Yersinia enterocolitica</i>	97,656	533	0.55	29	0.03
<i>Toxoplasma gondii</i>	86,686	4,428	5.11	327	0.38
<i>Listeria monocytogenes</i>	1591	1,455	91.45	255	16.03

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Vulnerable People and their Susceptibility to Foodborne Pathogens

In many cases previously healthy people recover well from foodborne illness, but in some cases the consequences are serious and long-term. In vulnerable people the consequences are liable to be much more serious, and to result from infection by lower numbers of a pathogen [6]. Many vulnerable people are those who have an immune system that is suppressed to some extent; these include the very young, the elderly, pregnant women and people whose immune system is suppressed by disease or by medication. It has been estimated that approximately 20% of the population in the USA has a compromised immune system [7,8].

Host factors that increase the risk of foodborne and waterborne infection and the severity of the disease are shown in table 3.

Many enteric pathogens show higher rates of reported infection in children < 5 years old than in older children and adults [10]. Scallan et al. [11] studied the effect of 4 major bacterial enteric pathogens causing foodborne illness in older adults, compared with the effect in other age groups (Table 4). The highest recorded rate of infection with NTS, *Campylobacter* and *E.coli* O157 was in the group aged < 5 years, while the highest rate of infection with *Listeria* was in adults aged > 65 years. For infection with each of the four pathogens the percentage of patients who died was higher in people aged > 65 than in the other age groups. After allowing for underreporting it was estimated that the highest number of deaths in the > 65 age group were caused by NTS and *L.monocytogenes*.

Non-typhoidal *Salmonella* spp. cause much more severe illness, including invasive and focal suppurative disease, in immune compromised than in immunocompetent adults [12,13]. Adults with diabetes, long-term steroid medication, haematological malignancy, advanced or disseminated solid cancers, autoimmune disease, liver disease, renal transplantation and people taking immunosuppressive drugs are susceptible to NTS bacteraemia. Patients with haematological malignancy were reported to be at increased risk of *Salmonella* or *Campylobacter* infection compared with people without malignancy [14], and in England and Wales in 2007 older persons (≥ 60 years, who are liable to be affected by chronic conditions) were the age group most at risk of campylobacteriosis [15]. Invasive disease due to *Campylobacter* spp. is reported to be rare, but is more frequent in people with comorbidities and immune-compromising conditions [16].

The relative susceptibilities of different subpopulations to *L.monocytogenes* are shown in table 5; data from the USA indicated that persons aged over 60 years were 2.6 times more susceptible than the general healthy population while perinatals were 14 times more susceptible. In pregnant women infection usually causes a mild, flu-like illness, but the bacterium can cross the placenta and infect the foetus, leading to abortion, stillbirth, or delivery of an acutely ill infant. Subsequent reports have confirmed the increasing risk with increasing age over 60 and the marked susceptibility associated with various types of cancer, particularly those associated with the blood [18-21]. The high level of risk in patients with AIDS (Table 5) has reduced considerably in some countries in recent years, probably as a result of the availability of antiviral therapy for HIV infection

Table 2: Estimates of quality-adjusted life year (QALY) loss and cost of illness for 5 main foodborne pathogens Data from [4].

	Annual foodborne illness cases	QALY loss	
		Per 1000 cases	Total Annual
<i>Salmonella</i> (non-typhoidal)	1,027,561	16.3	16,782
<i>Campylobacter</i> spp.	845,024	15.7	13,256
<i>Toxoplasma gondii</i>	87,786	124.9	10,964
<i>Listeria monocytogenes</i>	1,591	5892.4	9,375
Norovirus	5,461,731	0.9	5,027

Table 3: Host factors that increase the risk of foodborne and waterborne infection and/or the severity of the disease. Modified from [9].

Host factor	Reason for increased risk or severity
Primary immunodeficiency	Immune system inadequate to combat infection
Secondary immunodeficiency: resulting from leukemias, treatment with cytotoxic drugs during organ transplantation, for cancers or autoimmune disease, irradiation treatment, treatment with corticosteroids, infection with HIV.	Immune system inadequate to combat infection
Excessive iron in the blood	High levels of iron increase growth of certain pathogens
Cirrhosis and other liver disease, kidney function (alcoholism)	Iron overload, immune system dysfunction
Stress (e.g. as a result of surgery)	Changes in metabolism reduce resistance to infection
Diabetes	Poor glycaemic control is associated with impaired neutrophil functions
Pregnancy	Altered immunity
Age < 1 year	Gut microflora evolving, may allow survival of pathogens and colonization by spores of <i>Clostridium botulinum</i> . Lack of developed immune system.
Age < 5 years	Lack of developed immune system
Age > 60-65 years	Immune system deterioration, also affected by chronic ailments
Nutritional deficiency either through poor absorption of food or inadequate food supply	Immune system inadequate
Consumption of antacids, particularly proton pump inhibitors	Increase survival of pathogens in stomach
Consumption of large volumes of liquids including water	Dilution of acids in the stomach, rapid transit through stomach
Ingestion of fatty foods (e.g. chocolate, cheese, hamburger) containing pathogens	Fat protects pathogens from acid in stomach

Table 4: Average annual rate of laboratory-confirmed infections and deaths, due to 4 major foodborne pathogens in the US 1996-2012. Data from [11].

	Average annual rate of infection per 100,000 population			% of cases resulting in death		
	Age group, years					
	< 5	5-64	> 65	< 5	5-64	> 65
<i>Salmonella</i> (NTS)	64.7	11.2	12.8	0.1	0.3	2.4
<i>Campylobacter</i>	29.2	14.3	12.1	0.04	0.08	0.5
<i>Listeria</i>	0.5	0.1	1.4	5.4	11.1	21.9
<i>E.coli</i> O157	5.5	1.2	1.1	0.7	0.1	4.2
Total	99.9	26.9	27.4	0.13	0.22	2.6

Table 5: Relative susceptibilities of different sub-populations to listeriosis, based on French epidemiological data [17].

Condition	Relative susceptibility
Transplant	2584
Cancer- blood	1364
Acquired immunodeficiency syndrome (AIDS)	865
Dialysis	476
Cancer - pulmonary	229
Cancer – gastrointestinal/liver	211
Noncancer liver disease	143
Cancer – bladder and prostate	112
Cancer - gynaecological	66
Diabetes – insulin-dependent	30
Diabetes – noninsulin-dependent	25
Alcoholism	18
Perinatals*	14
Aged > 65 years	7.5
Less than 65 years, no other condition (reference population)	1

*information from the USA.

[20]. Use of cytotoxic drugs, drugs affecting the immune response, and corticosteroids resulted in particular susceptibility to listeriosis [22]. Risk factors for death as a result of listeriosis included particular malignancies, alcoholism, cardiovascular disease, increasing age, and treatment to reduce gastric secretion; some previous workers also identified steroid medications and kidney disease/renal failure as independently associated with mortality [23].

Infection by the parasite *T.gondii* can lead to serious illness, particularly in pregnant women and their infants and in people with impaired immunity [24,25]. Following infection, pregnant women may not show symptoms of infection, but the organism may spread to the foetus and can lead to miscarriage, stillbirth, and severe disease in the newborn or development of disease later in infancy, childhood or adolescence [26].

In immunocompetent people infection with *T.gondii* is generally asymptomatic, but can result in lymphadenopathy, ocular symptoms (chorioretinitis) or occasionally effects on the central nervous system; following infection, the organism can persist as cysts in various tissues of the body, particularly in the brain, retina and muscles. In immunocompromised people toxoplasmosis can result from primary infection or from reactivation of latent cysts, which can occur if there is a decline in the person's immune system, particularly in AIDS, transplant and cancer patients [27-29] and can lead to ocular, cerebral or disseminated toxoplasmosis. Toxoplasmosis is a significant cause of eye disease in the USA [30]. Cats are the definitive host of *T.gondii* and can shed infective oocysts in the environment; these oocysts may result in infection of other animals. Human infection can result from consumption of water or vegetables contaminated by oocysts from cat faeces, or from consumption of undercooked meat or raw milk of infected animals. Because of the risk of transfer of oocysts from cat faeces, pregnant women and immunocompromised people are advised to wear gloves when gardening or handling soil or sand from sand boxes and to wash their hands thoroughly afterwards [24]. If possible, these groups should also avoid changing cat litter boxes, which should be changed daily, and cats should not be fed raw meat. In view of the potential risk posed by latent cysts in immunocompetent people if they become immunocompromised, the advice given above is appropriate for the general population. There are differences in the detailed advice given in European countries and the USA [25].

Foodborne infection with norovirus can result in extensive person-to-person spread of the virus. In immunocompetent people norovirus infection usually results in gastroenteritis lasting 24-48h and is self-limiting, but the virus can be shed in the faeces for 20-40 days [31]. In immunocompromised people the gastroenteritis can be chronic and can persist for weeks or years. Prolonged norovirus-associated diarrhoea can result in malnutrition, dehydration, and altered intestinal mucosal barrier [32].

Main Foods Associated with Hazards

Based on estimated disease burden, in terms of loss of Quality-Adjusted Life Years (QALY) and cost of illness the top 50 pathogen-food combinations in the USA were ranked by Batz et al. [33], the top 14 of which are shown in table 6. An estimate of the main pathogen-food combinations, based on studies in the literature, is shown in table 7. Foods of animal origin are associated with the major proportion of cases of foodborne illness, but foods of non-animal origin are also associated with many outbreaks and cases. In the USA top-ranking risk groups of non-animal foods were listed as: (1) *E.coli* O157:H7 and leafy greens, (2) *Salmonella* and tomatoes, (3) *Salmonella* and leafy greens, *Salmonella* and melons, (4) *E.coli* O157:H7 and crucifers and melons [35]. In the European Union the top-ranking risk groups were listed as: (1) *Salmonella* and leafy greens eaten raw, (2) *Salmonella* and bulb and stem vegetables, *Salmonella* and tomatoes, *Salmonella* and melons, and pathogenic *E.coli* and fresh pods, legumes or grains [36].

Main Factors Leading to Transmission of Foodborne Pathogens

Five main factors leading to transmission of foodborne pathogens have been listed by the FDA [37].

These include:

- Food from unsafe sources
- Inadequate cooking
- Improper holding temperatures
- Contaminated equipment
- Poor personal hygiene

Examples of outbreaks that have resulted from such factors are shown table 8.

Many cases of toxoplasmosis appear to be sporadic, and outbreaks

Table 6: Ranking of disease burden for major pathogen-food combinations in the USA based on loss of QALY and cost of illness. Data from [33].

Rank	Pathogen-food combination
1	<i>Campylobacter</i> -poultry
2	<i>T.gondii</i> -pork
3	<i>L.monocytogenes</i> - deli meats
4	<i>Salmonella</i> NTS- poultry
5	<i>L.monocytogenes</i> - dairy products
5	Norovirus- complex foods
7	<i>Salmonella</i> NTS- complex foods
8	<i>Salmonella</i> NTS -produce
8	<i>T.gondii</i> - beef
10	<i>Salmonella</i> NTS - eggs
11	<i>L.monocytogenes</i> – complex foods
12	<i>Salmonella</i> NTS - beef
13	<i>Salmonella</i> NTS - pork
14	Norovirus – produce

Table 7: Foods associated with disease caused by major foodborne pathogens. Information derived from studies in several countries. Data from [34].

Pathogen	Foods
<i>Campylobacter</i>	Poultry, 40%-70%; dairy, 10%-40%; unspecified red meat up to 40%.
Norovirus	Seafood up to 40%; produce 20-40%; complex and other foods up to 10%.
<i>Clostridium perfringens</i>	Beef and lamb 40%-50%; poultry up to 20%; complex foods, up to 20%.
<i>Salmonella</i>	Eggs, 10%-80%; poultry, up to ~40%; produce, up to 20% pork, beef and lamb, each up to 20%; complex foods up to 20%.
<i>E.coli</i> O157	Beef and lamb, 40% - 70%; produce, 10% - 30%.
<i>L.monocytogenes</i>	Unspecified meat, up to 50%; dairy products, up to 40%; complex foods, up to 40%, seafood up to 20%; other meats, up to 20%; produce, up to 10%.

are rarely detected because many individuals affected show few or no immediate symptoms. A number of outbreaks, mainly affecting a few people, were described by Smith [26]. These were associated mainly with consumption of raw meat or raw goat milk.

Prevention of Foodborne Disease

Detailed advice on the provision of safe food in retail and in food service is given in the FDA Food Code [37].

Table 8: Examples of outbreaks of foodborne disease.

Place/date	Causative organism	Setting	Cases (hospitalized) (deaths)	Food implicated	Factors leading to outbreak	Susceptibility of patients	Reference
Austria, 2006	<i>C.jejuni</i> , <i>C.coli</i>	Tertiary care hospital	7 (0) patients 14 (0) staff	Poultry dishes	Prepared in hospital kitchen, cook-chill system, no HACCP in place	nr	[38]
UK, 2011	<i>C.jejuni</i> , <i>C.coli</i>	Wedding party	40 (0) {0}	Chicken-liver pâté	Undercooked (cooked to 60°C)	nr	[39]
US, 2012	<i>C.jejuni</i>	Community	148 (10) {0}	Unpasteurized milk	No inactivation	No information, median age 31 years range 2-74 years	[40]
USA, 2012	<i>C.jejuni</i>	Community	6 (2) {0}	Chicken liver	Undercooked	nr	[41]
USA, 2001	<i>Clostridium perfringens</i>	Residential care facility for mentally ill	7 (2) {2}	Thanksgiving meal with turkey	Large amount of food prepared well in advance of serving	Deaths associated with constipation resulting from medication	[42]
UK, 2005	<i>Clostridium perfringens</i>	Buffet lunch at event	54 (nr) {nr}	Chicken curry	Prepared in a domestic kitchen, not registered with local authority, bulk of cooked curry left to cool at ambient temperature	nr	[43]
USA, 2010	<i>Clostridium perfringens</i>	Psychiatric hospital	43 {3} patients 12 {0} staff	Cooked chicken	Cooked ~24h before serving, not cooled adequately	Deaths associated with impaired intestinal motility	[44]
Germany, 2011	<i>E.coli</i> O104:H4	Community	> 3800 (~800) {> 50}	Raw, sprouted seeds (fenugreek)	Difficult to disinfect before sprouting	nr	[45,46]
USA, 2012	<i>E.coli</i> O157	Schools, day care centres, long-term care facilities	17 (6) {2}	Packaged, salad lettuce	Possible contamination during growth in field	nr	[47]
USA, 2012-2013	<i>E.coli</i> O157	Community	17 (0) {0}	Raw ground beef	Traditional practice, previous reported outbreaks	nr	[48]
Canada, 2008	<i>L.monocytogenes</i>	Community, long-term care facilities, hospital	57{24}	Delicatessen meat	Contaminated meat slicers used during production	41 patients in long-term care facilities or hospital inpatients	[49]
Denmark, 2009	<i>L.monocytogenes</i>	Meals-on-wheels	7 (7) {2}	Sliced beef with sauces and vegetables, intended for microwave cooking by consumer	Beef had been cooked by supplier at a lower temperature than usual	Four patients had cancer, one had systemic lupus erythematosus, three were aged >80.	[50]
USA, 2010	<i>L.monocytogenes</i>	Hospital	10 (10) {5}	Diced celery, often in sandwiches	Probably contaminated in the field	All 10 patients immunocompromised or were receiving corticosteroid steroid or acid-reducing treatment	[51]
USA, 2011 (28 states)	<i>L.monocytogenes</i>	Community	147 (143) {33}	Cantaloupe melon	Contamination during washing and processing of fruits on a single farm. No sanitizing.	86% were aged ≥ 60 years. 88% had potentially immunosuppressive illness or were receiving immunosuppressive therapy.	[52]
Denmark, 2005	Norovirus	Hospital, nursing homes, meals-on-wheels service, restaurant, company canteen	> 1000 (~400) {0}	Imported, frozen raspberry pieces	Probable contamination during growth/harvesting on small farms	nr	[53]
Austria, 2009	Norovirus	Hospital, rehabilitation centre and convalescent home	114 {0} patients and staff affected	Sliced, cold sausage, meat dish with salad, spinach pancake	Contamination by one of five asymptomatic excreters among kitchen staff who prepared food.No HACCP in place	nr	[54]
UK, Norway, France, Sweden, Denmark, 2010	Norovirus	Mainly restaurants	334 (nr) {nr}	Oysters	Probably contaminated in oyster-growing areas and inadequately cooked.	nr	[55]
France, 2012	Norovirus	Nursing home	84 [53 residents, 31 staff] (1) {1}	Raw Oysters	High risk of norovirus contamination of oyster-growing areas. No	nr Initial cases related to consumption of oysters, later cases due to person-to-person transmission	[56]

USA, 2002	S.Enteritidis	Hotel & conference centre	617{0}	Probably contaminated sauces	Sauces prepared by an infected, asymptomatic sous chef	nr	[57]
USA, 2007	S. enterica	Community	396 (108) {3}	Frozen pot pies, chicken, turkey, beef	Possible cross-contamination during production. Instructions given for microwave cooking inadequate to ensure full cooking	Median age of consumers 20 years range 1 month to 97 years.	[58]
Netherlands, 2012	S.Thompson	Community	Confirmed cases 1,149 (39 of 112 cases hospitalised) {4 died} Estimated total cases 23,000 (650) {24}	Smoked salmon	Use of reusable dishes on processing line, dishes were porous and became loaded with the salmonella	Four reported deaths in persons aged 76-91 years.	[59]
USA, 2014	S.Typhimurium, S.Newport	Community	275 (48/141) {1}	Cucumbers	nr	nr	[60]
Canada, 1995	T.gondii	Community	Probably between 2894 and 7718 people affected, of whom 100 showed symptoms	Municipal drinking water	Probable contamination of reservoir by runoff containing oocysts from cat family	nr	[61]
Korea, 1994	T.gondii	Community	3	Raw Boar meat	Tissue cysts liable to be present in boar meat	Healthy adults, 2 lost sight in one eye	[62]
Korea, 1995	T.gondii	Squadron of soldiers	5	Raw pork	Tissue cysts liable to be present in pork	Healthy adults, lymphadenopathy	[62]

nr = not reported

Control of food production

The FDA Food Code [37] recommends, and European regulations [63] require that food business operators should put in place, implement and maintain a permanent procedure or procedures based on hazard analysis and critical control point principles (HACCP). The HACCP plan is designed to provide safety from biological, chemical and physical hazards, and includes the following actions:

- (1) Identify any hazards
- (2) Identify the critical control points (CCPs); - the points at which control is needed to prevent, remove or reduce a hazard in the process
- (3) Set critical limits to assure that the operation is under control at a particular control point
- (4) Establish and implement monitoring systems at control points
- (5) Take corrective action when critical limits are not met
- (6) Have checks in place to verify that the system is working
- (7) Keep records

This applies to meals supplied in hospitals and institutions as well as other food businesses. In order for a HACCP system to be effective, prerequisite programs must be in place to control the basic

operational and hygiene conditions (including Good Manufacturing Practice) within an operation [37].

Avoid food from unsafe sources

The FDA Food Code specifies that food should be obtained from sources that comply with the law [37]. Food prepared in a private home may not be offered for human consumption in a food establishment. Specifications are included regarding the source and labelling of specific types of food. Special requirements are included for foods prepared in an establishment that serves a highly susceptible population.

Ensure adequate cooking

Conditions advised for cooking foods (Table 9) are based on a requirement to inactivate vegetative microbial pathogens including *Campylobacter* spp, STEC, NTS and *L.monocytogenes*, the most heat-resistant of this group.

Ensure control of holding temperature

Clostridium spp., including *Clostridium perfringens*, form spores that are heat-resistant and are not inactivated by cooking. In order to prevent foodborne illness due to *C.perfringens* meals, particularly meat dishes that are not eaten immediately but are prepared in advance, should be cooled within two hours from 57°C to 21°C and within 6 hours from 57°C to 5°C [37]. These meals should not be allowed to remain at temperatures between 12°C and 50°C, which can allow the surviving spores of *C.perfringens* to germinate and the vegetative

Table 9: Temperatures and times advised for thorough cooking of animal foods. A food thermometer should be used to check the internal temperature reached throughout the food.

Food	Temperature to be reached in all parts of the food	Time at specified temperature	Reference
Meat, eggs ,seafood, minced meats, rolled roasts, large joints of meat, whole poultry, soups, stews, poultry	70°C	Instantaneous	[64]
Burgers (ground, minced meat), poultry livers and other foods	70°C or equivalent temperature/time combination	At least 2 min	[65-67]
Raw eggs broken and prepared for immediate service, Fish, meat poultry except as specified below	63°C (145°F) or above	15s	[37]
Mechanically tenderized meat, injected meats, ratites, comminuted fish, meat, game animals commercially raised for food, raw eggs not prepared for immediate service	68°C (155°F)	15s	[37]
	70°C (158°F)	Or equivalent combination	
	66°C (150°F)	Instantaneous	
	63°C (145°F)	1 min	
Whole meat roasts including beef, corned beef, pork, cured pork, stuffed ratities, stuffing containing fish, meat, poultry of ratites	74°C (165°F) or above	3 min	[37]
Raw animal food cooked in a microwave oven	At least 74°C (165°F) throughout the food	15s	[37]
		Instantaneous. Allow to stand for 2 min after cooking	[37]

bacteria to multiply to numbers that can cause food-poisoning after consumption of the meal. Meals that are prepared and stored should be reheated to at least 74°C for 15 sec before consumption [37].

Freezing can inactivate tissue cysts of *T.gondii* in meat. Tissue cysts in pork were usually inactivated by freezing at an internal temperature of -12.37°C, but survived freezing at -6.7°C for up to 11 days [68].

Chilled foods should be maintained in a refrigerator at 5°C or lower, to reduce growth of food-poisoning bacteria and maintain the safety and quality of the food.

L. monocytogenes can grow slowly at temperatures as low as 3-5°C.

Prevent contamination of equipment

Food contact surfaces, including meat slicers, should be cleaned thoroughly. Raw foods and ready-to-eat foods should be well-separated. Separate equipment and utensils should be used for raw and cooked food.

Maintain good personal hygiene

For food handlers, personal cleanliness and good hygienic practices are essential. In the section on Employee Health the FDA Food Code [37] gives full information on the conditions that food employees must meet to avoid transmitting foodborne disease. It lists symptoms that a food handler must report to the person in charge and conditions that require workers to be restricted or excluded from working in a food establishment. *Restriction* means that a food employee's activities are limited to prevent the risk of transmission of disease via food i.e. there is no contact with exposed food or food-contact materials. *Exclusion* means that a food employee is not permitted to work or enter a food establishment as an employee.

A food employee should be *excluded* from a food establishment if the person shows symptoms of vomiting or diarrhoea caused by an infection, or has symptoms diagnosed as due to an infection with norovirus, *Shigella* spp., NTS or STEC. A person diagnosed with hepatitis A infection within 14 days from the onset of any illness symptoms, or within 7 days of the onset of jaundice or who has not developed symptoms should also be *excluded*. A food employee who is diagnosed with an infection with *S.Typhi* or reports a previous infection with *S.Typhi* within the past 3 months should be *excluded*.

A person who is diagnosed with an infection with norovirus,

Shigella spp., STEC, but is asymptomatic, should be *excluded* from working in a food establishment serving highly susceptible people, or *restricted* from working in a food establishment not serving a highly susceptible population. A person diagnosed with non typhoidal *Salmonella* infection and is asymptomatic should be *restricted* from working in a food establishment that serves a highly susceptible population, or in an establishment not serving a highly susceptible population.

A person ill with symptoms of acute onset of sore throat and fever should be *excluded* from working in a food establishment serving a highly susceptible population, or *restricted* from working in a food establishment not serving a highly susceptible population. A food employee with a skin lesion containing pus that is open and not properly covered should be *restricted* from working as a food employee.

A person who has been exposed to a foodborne outbreak or case involving norovirus, (in the past 48 hours), STEC or *Shigella* (within the past 3 days), *S.Typhi* (within the past 14 days) or Hepatitis A virus (in the past 30 days) should be *restricted* from working in a food establishment that serves a highly susceptible population.

The conditions in which *restricted* or *excluded* persons are again allowed to work in a food establishment [1] not serving a highly susceptible population or [2] serving a highly susceptible population, are outlined in the US Food Code [7]. Comparable guidance for food handlers is published in the UK [69].

Selection of Lower-Risk Foods

The FDA has issued guidance for people at risk of foodborne illness, including Older Adults, People with Cancer, and people with Diabetes, people with HIV/AIDS, Pregnant Women, and Transplant Recipients [5]. In each case the advice includes a similar section on the selection of lower-risk foods (Table 10). More detailed 'low risk diets' ('low-microbial diets' or 'neutropenic diets') are advised by many hospitals and other organizations, for highly immunosuppressed people [70-77].

These diets aim to omit higher-risk foods, identified as potential sources of organisms that cause infection especially in immunocompromised people, and substitute lower-risk (safer) foods. In relation to listeriosis, high-risk foods are defined as foods with the following properties: (i) have the potential for contamination with *L.monocytogenes* (ii) support the growth of *L.monocytogenes* to high

Table 10: Food safety for people with cancer [5]. Common foods: Select the lower-risk options.

Type of food	Higher-risk	Lower-risk
Meat and poultry	Raw or undercooked meat or poultry	Meat or poultry cooked to a safe minimum internal temperature
<i>Tip: Use a food thermometer to check the internal temperature on the "Is it done yet?" chart for safe minimum internal temperature.</i>		
Seafood	Any raw or undercooked fish or shellfish or food containing raw or undercooked seafood e.g. sashimi, found in some sushi or ceviche. Refrigerated smoked fish. Partially cooked seafood, such as shrimp and crab	Previously cooked seafood heated to 165°F Canned fish and seafood Seafood cooked to 145°F
Milk	Unpasteurized (raw) milk	Pasteurized milk
Eggs	Foods that contain raw/undercooked eggs, such as: Homemade Caesar salad dressings Homemade raw cookie dough Homemade eggnog	<i>At home</i> Use pasteurized eggs/egg products when preparing recipes that call for raw or undercooked eggs <i>When eating out:</i> Ask if pasteurized eggs were used
<i>*Tip: Most pre-made foods from grocery stores, such as Caesar dressing, pre-made cookie dough, or packaged eggnog are made with pasteurized eggs.</i>		
Sprouts	Raw sprouts (alfalfa, bean, or any other sprout)	Cooked sprouts
Vegetables	Unwashed fresh vegetables including lettuce/salads	Washed fresh vegetables, including salads. Cooked vegetables
Cheese	Soft cheeses made from unpasteurized (raw) milk, such as: Feta, Brie Camembert Blue-veined Queso fresco	Hard cheeses Processed cheeses Cream cheese, Mozzarella, Soft cheeses that are clearly labelled "made from pasteurized milk"
Hot Dogs and Deli meats	Hot dogs, deli and luncheon meats that have not been reheated	Hot dogs, luncheon meats and deli meats reheated to steaming hot or 165°F
<i>Tip: You need to reheat hot dogs, deli meats and luncheon meats before eating them because the bacteria, Listeria monocytogenes grows at refrigerated temperatures (40°F or below). This bacteria may cause severe illness, hospitalization or even death. Reheating these foods until they are steaming hot destroys these dangerous bacteria and makes these foods safe for you to eat.</i>		
Pâtés	Unpasteurized, refrigerated pâtés or meat spreads	Canned or shelf-stable pâtés or meat spreads

numbers (iii) are ready to eat (iv) require refrigeration, and (v) are stored for an extended period of time [78].

There have been several criticisms of low-microbial diets; from a review of randomized, controlled trials comparing the effect of use of a low-microbial diet with a control diet on infection rate, it was concluded that the three main studies had serious methodological limitations, and no definitive conclusions could be drawn [79]. There are differences in detail between some of the low-microbial diets, but the essential feature of avoiding foods that are known to have the potential to transmit foodborne pathogens, and substituting safer foods providing similar nutritive value, is clearly important to ensure that vulnerable people do not suffer severe consequences as a result of foodborne infection.

More general agreement on such recommendations would be valuable, and as new information about the microbiological safety of foods becomes available such diets may need to be modified.

Conclusions

Up to 20% of people in the US, UK and other industrialised countries are particularly vulnerable to foodborne disease. Procedures are available that are designed to minimize this risk. These procedures need to be recognised universally and to be implemented. According to Silk et al. [80] "evidence for the problem of unsafe food preparation and service for immune compromised and elderly patients is not only widespread, but also underestimated and can be expected to grow". They stressed that professional organisations should promote, and large healthcare systems should establish, policies to prepare safe food for immune compromised patients, and not serve them higher-risk foods. The same care is needed in the provision of food for immune compromised persons in the community.

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