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COMMENTARY

Death by food

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Abstract Although death from food is not an uncommon finding in forensic facilities worldwide, the range of underlying lethal mechanisms and associated conditions that should be sought at the time of autopsy is quite disparate. Deaths may occur from i) infectious agents including bacteria, viruses, protozoa, cestodes, nematodes and prions; ii) natural toxins including amanita toxins, tetrodotoxin, ciguatera and scombroid; iii) anaphylaxis; iv) poisoning; v) mechanical issues around airway and gut obstruction and/or perforation; and vi) miscellaneous causes. Food-related deaths are important in terms of global mortality, and thus autopsies need to be comprehensive with full ancillary testing. Medicolegal matters may involve issues concerning likely exposure to infectious agents, possible foods ingested, the declared content and possible components of food, the significance of toxicological analyses, and aspects of duty of care in cases of café coronary syndrome and gastroenteritis while in care.

Keywords Food · Infections · Gastroenteritis · Toxins · Poisoning · Café coronary

Unquiet meals make ill digestions.
Richard III Act 3 Scene 4.
William Shakespeare 1564–1616.

This paper is dedicated to the memory of Mr. Sperry Morgan, a patient at the Repatriation General Hospital, Hobart, Tasmania, 1983.

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Introduction

There is currently a fascination with food preparation and consumption in the West with exotic and under-cooked meals being encountered more and more often. However, the simple act of eating may come at a cost, with food being responsible for millions of deaths globally from an array of quite disparate mechanisms. There are literally hundreds of microbial, chemical and physical agents that can cause illness if consumed [1]. As forensic pathologists continually deal with cases of death by food the following provides an overview of common, rare and culturally-specific forms of death caused by the deliberate or inadvertent consumption of pathogens, toxins and foodstuffs (Table 1).

Infections

Infection is a major issue, as food provides an excellent transport media for bacteria, viruses, parasites and even prions. This resulted in a death toll of approximately 1.8 million people from diarrhea globally in 2005, due most likely to the consumption of contaminated water and/or food. In 1999 it was estimated that 5000 deaths occurred in the United States annually from foodborne agents [2, 3]. Common bacteria include *Salmonella spp*., *Campylobacter spp*. and *Escherichia coli*. These bacteria are readily able to adapt to their environments, with increasing antibiotic resistance and changes in activity; for example *Salmonella*, which is typically found in dairy products, pork, poultry and beef, is now able to colonize vegetables [2]. *Campylobacter* is found in poultry, *Shigella* and *Vibrio* in seafood (the latter particularly in raw oysters) and *Listeria monocytogenes* in prepared prepackaged foods (as it is capable of surviving refrigeration temperatures) [3, 4].

Table 1 Causes of fatalities due to food ingestion

Infectious agents
Bacteria
Viruses
Protozoa
Cestodes
Nematodes
Prions
Natural toxins
Amanita related
Tetrodotoxin
Ciguatera
Scombroid
Anaphylaxis
Poisoning
Mechanical issues
Airway obstruction
GIT obstruction
GIT perforation
Miscellaneous

A number of issues have been identified that have led to increases in infective foodborne illnesses and deaths. These include an aging population with more immunologically compromised individuals (heightened vulnerability), more exotic or under-cooked/raw meals (greater exposure to pathogens), increased organic farming, a global marketplace for vegetables, fruit and meat (that are sometimes sourced from countries with suboptimal monitoring of standards), changing farming practices, increased movement of human populations, and faster transport of ingredients/foodstuffs (facilitating pathogen survival) [2, 5].

Food manipulation such as the use of transglutaminase as "meat glue" to "restructure" "low-value cuts and trimmings" [6] by fusing scraps of meat together, may also result in bacteria being trapped within an apparent single piece of meat. Undercooking may then result in inadvertent exposure to these pathogens from the non-sterile center of the meat.

Bacteria can cause disease by direct invasion of intestinal mucosal cells causing ulceration as in *Salmonella*, *Shigella*, *Campylobacter* and *Yersinia* (Figs. 1 and 2), through preformed toxins as in *Clostridium botulinum* and *Staphylococcus aureus,* or by producing toxins within the intestine as in *Vibrio spp*., *Clostridium perfringens* and Shiga toxin-producing *Escherichia coli* [1, 7, 8]. Sudden deterioration and death can result from dehydration, fluid and electrolyte imbalances, shock, intestinal perforation, and disseminated intravascular coagulation [9–12].

There are marked regional differences in the occurrence of many of these conditions and so case profiles in forensic morgues will have considerable geographic variability. For

Fig. 1 The small intestine in a 78-year-old man who died on admission to hospital following a 24-h history of diarrhea and vomiting. Salmonella septicemia was diagnosed. The small intestine is edematous with small ulcers and adherent exudate. Microscopy showed a marked inflammatory infiltrate of the submucosa with ulcer slough containing colonies of bacteria

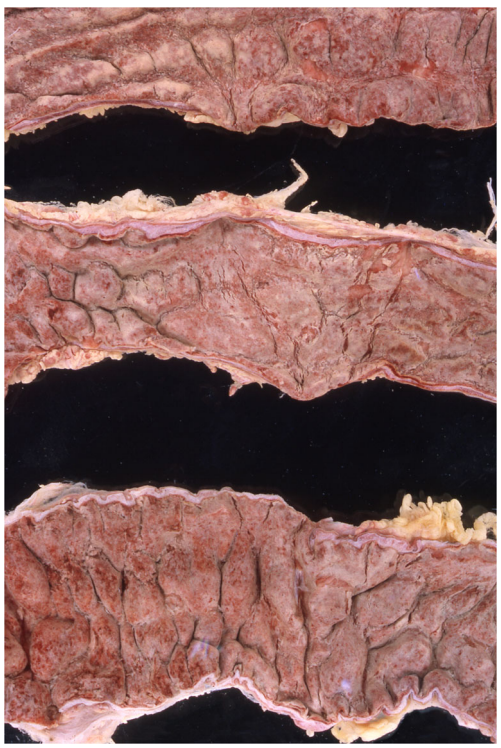

Fig. 2 The large intestine of an 8-year-old girl who died of bacillary dysentery due to *Shigella* spp. The intestine is edematous with submucosal hemorrhage

example, in 2010 there were approximately 13.5 million cases of typhoid fever globally, with 210,000 related deaths reported in 2000. However, the incidence of typhoid in Central Asia and Central/Eastern Europe of <0.1/100,000 contrasts markedly with 724/100,000 in Sub-Saharan Africa [13].

Viruses do not grow in food but are encountered due to fecal contamination or from an animal reservoir such as the SARS coronavirus where the infection appears to have come from bats, and the H5N1 avian influenza virus that has been found in duck meat [2]. Parasites that may cause lethal disease include protozoa such as *Toxoplasma gondii* and *Cryptosporidium spp*. that may be found in beef, pork and milk, and cestodes such as *Echinococcus* that may come from raw vegetables and unwashed fruit [2, 14, 15]. Rarely *Ascaris* infection (found in vegetables) may lead to acute upper airway occlusion and *Taenia solium* (found in beef or pork) may cause death from epilepsy or acute hydrocephalus [9].

Prion disease picked up from contaminated food may be a rare cause of death from spongiform encephalopathy. For example, bovine spongiform encephalopathy (mad cow disease) is a recently identified (1987) condition related to Creutzfeldt-Jacob disease and scrapie in sheep [16, 17].

Culture-specific practices may also result in particular types of lethal foodborne diseases and 'pig-bel' (pig belly) is a very good example of this. This disease is a form of patchy necrotizing enteritis that is found in children in the Highlands of New Guinea following massive feasting after pig kills (Figs. 3 and 4) [18]. The meat is steamed in earth pits but studies have shown that large portions are not thoroughly cooked using this method. This results in exposure to *Clostridium perfringens* Type C toxin with clinical presentations of severe enteritis, toxemia and shock resulting in a mortality rate of 85% in the most acutely ill group. 'Darmbrand' was a similar condition that was found in north-west Germany towards the end of, and just after, World War II due to *Clostridium perfringens* Type F in food [19, 20].

Fig. 4 Focally necrotic jejunum from a 12-year-old boy from the Eastern Highlands of Papua New Guinea who developed necrotizing enterocolitis ("pig bel") after eating pork at a local pig kill. The intestine is ulcerated with gas cysts within the submucosa

The prion disease Kuru is also another example of an illness shaped by cultural practices. This condition, found

Fig. 3 A pig kill in the Highlands of Papua New Guinea showing racks of pork meat about to be cooked in earth trenches

among the Fore people of the Eastern Highlands of New Guinea, results in a steadily progressing dementia arising from the ritual consumption of relatives' brains [18]. Handling infected brains causes inoculation of the organisms through the skin. However, with the abolition of endocannibalistic mortuary rituals among the Fore, the numbers of cases of Kuru have dropped from 200 per year in the late 1950's to one to two per year in more recent times [21].

Natural Toxins

Toxins may also be consumed directly with food. A classic example of this is poisoning with the mushroom *Amanita phalloides* or "death cap" which has become more prevalent in recent times with the interest in "foraging" leading to the consumption of edible wild mushrooms [22, 23]. Amatoxins in the mushrooms cause a sudden onset of nausea, vomiting and bloody diarrhea that is followed by progressive liver and kidney failure, coma and death [24]. Casper reported that there may have been complaints of "a disagreeable harsh taste in the throat" with "a feeling of disgust" [25].

Puffer fish toxicity is the most common type of poisoning in certain Asian coastal communities partly due to its availability and low cost. These fish contain tetrodotoxin, a neurotoxin which is concentrated in the gonads, liver, skin and intestine [26]. Puffer fish is also served as the delicacy "fugu" in certain Japanese restaurants. The toxin causes ascending paralysis with eventual respiratory failure, with death sometimes occurring within hours of ingestion [27]. The toxin has been found in other marine and terrestrial species and is produced by eukaryotic dinoflagellates in saltwater and prokaryotic cyanobacteria in freshwater [27].

A more common cause of fish poisoning globally is ciguatera, where affected fish have accumulated ciguatoxins from dinoflagellate organisms such as *Gambiersdiscus toxicus*. Symptoms include diarrhea and vomiting with hypotension, bradycardia and neurological problems such as paresthesiae and peripheral neuropathy. Rarely death may occur [28]. Although it is endemic to tropical and subtropical locations, concern has been raised about the possible effects of increasing international trade in tropical and exotic fish [29].

Dinoflagellates and diatoms may also be responsible for food poisoning when filter-feeding shellfish such as mussels or oysters take up toxins that these micro-organisms produce. This is most likely to occur during blooming when there is a so-called "red tide" [30, 31]. This was exemplified by Henry Buttes in the sixteenth century when he wrote that "it is unseasonable and unwholesome in all months that have not an R in their names to eat an oyster" as these are the months when blooms usually occur. Captain George Vancouver lost a crew member who had eaten mussels during his exploration of the Pacific Coast in 1789, and more recently, again in Canada, three deaths occurred in 1987 after the consumption of cultivated mussels contaminated with *Pseudo-nizschia multiseries* [30, 31].

Scombroid poisoning, also referred to as histamine fish poisoning, occurs when raw fish has been improperly refrigerated resulting in a breakdown of histidine into histamine by bacteria. This produces symptoms and signs that are similar to an allergic reaction that may have particularly serious consequences in individuals with underlying cardiorespiratory disease [32]. While the original cases involved mackerel and tuna (*Scombridae* spp.), it has now been reported in a wide variety of species including herring (*Clupea* spp., sardines (*Sardinella* spp.), pilchards (*Sardina pilchardus*), anchovies (*Engraulis* spp.) and mahi-mahi (*Coryphaena* spp.) [32].

Anaphylaxis

Anaphylaxis refers to the cascade of immunological and clinical events that follow exposure to a particular antigen. Multiple organs are involved, particularly the skin, respiratory, cardiovascular and neurological systems. It is usually mediated by immunoglobulin E (IgE) as a type I hypersensitivity reaction to a foreign material which includes food [33, 34]. The prevalence of allergic conditions has "more than doubled" in the last twenty years [35] with a specific increase in food-related anaphylaxis, particularly in younger children (0 to 4 years) [36]. Cases of peanut allergies in children have increased in Australia, the United Kingdom and the United States [37].

Anaphylactic reactions to food most often involve peanuts, other nuts, milk and fish, or other seafoods [38]. Death may occur very rapidly due to a combination of upper airway obstruction from mucosal edema, asphyxia from bronchospasm, and shock due to massive fluid shifts. Thromboembolic and hemorrhagic events may also occur [34]. There are an estimated 10 cases of food-related anaphylactic fatalities each year in the United Kingdom [39]. This may, however, be an underestimate as cases may be difficult to diagnose at autopsy as there may be no macroscopic markers present, although elevated serum tryptase levels may be a useful clue [40].

The increase in cases of food anaphylaxis in recent years may be due to alterations in gut commensal microbiota [41] possibly caused by dietary factors or by increasing exposure to antibiotics. Although this appears to be particularly so in children, rates are now increasing in adolescents and young adults. The prevalence of food allergy amongst preschool children in Australia and the United Kingdom is between 5 to 10% [42, 43]. New food labelling legislation has been enacted in response to this trend, but is not without problems, and forensic practitioners can undoubtedly expect to see an increase in both civil and criminal cases related to food allergy deaths in the future [39, 44]. While in most case exposure to food allergens is unintentional, it has rarely been found in suicides [45].

Poisoning

Poisons in foods may be due to an unrecognized contaminant, or to deliberate addition of material in cases of homicide. In previous years poisoning of food to dispatch victims was achieved using arsenic, cyanide, mercury, strychnine and opium, amongst others [25, 46]. For this reason food tasters were often employed in the Roman Empire and in Ancient Egypt to sample meals before the emperor or ruler dined. This was not always completely successful, however, as the Emperor Claudius discovered when he was poisoned in A.D. 54 despite (? because of) the efforts of Halotus, his official taster [47].

Heavy metal within food is occasionally reported from environmental sources such as the case of Minamata disease. This refers to an outbreak of methyl mercury (MeHg) poisoning among the residents of Minimata Bay in Japan due to heavy contamination of fish and shellfish from a nearby chemical plant. This resulted in neurological disturbances and birth defects rather than death [48], although it has been suggested that chronic exposure to MeHg may increase the likelihood of subsequent cardiac events [49]. The use of grain contaminated with mercury to bake bread in Iraq in the 1970's did result in the deaths of several thousand people [50].

The hypothesis that Sir John Franklin's men died in the Arctic following exposure to lead contamination from preserved food in metal cans is no longer supported following metal analyses of a finger and toenail from a crew member who died on Beechey Island in 1845–46 [51].

Mechanical Issues

Acute airway occlusion may occur in individuals who have unsuccessfully attempted to swallow a large bolus of food. Termed "café coronary' syndrome by Haugen in 1963 risk factors include: i) neurological diseases such as dementia, multiple sclerosis, Parkinson disease, cerebrovascular disease, bulbar palsy, cerebral sarcoidosis and Huntington chorea; ii) psychotropic drugs and/or alcohol; iii) psychiatric conditions such as mental impairment, schizophrenia, polyphagic/tachyphagic syndrome and obsessive compulsive disorder; iv) local disease such as dental disease, tumors and xerostomia; and v) age [52–54]. Although the usual obstructing food is poorly masticated meat, any material, including feces, may be ingested by demented individuals with resultant airway occlusion [55]. It has also been reported in animals [56]. Issues of duty of care may be raised with such deaths in nursing homes. On occasion, however, airway obstruction may occur without any obvious risk factors [57].

While airway obstruction from a food bolus is usually found in the elderly with the above conditions, it has also been identified in the very young. In these situations toddlers have often been fed fruit such as apples, or vegetable such as carrots. The eruption of incisor teeth before molars means that while they are able to bite off chunks of solid food, they are not able to appropriately masticate, predisposing to choking [58]. Episodes of fatal choking resulting from lack of adequate supervision during meal times in childcare centers have been termed "crèche coronaries" and require the implementation of appropriate feeding guidelines [58, 59]. Rounded foods such as sausages and grapes are more likely to cause obstruction [60].

Although obstruction of the upper airway occurs, the rapidity of collapse raises the possibility of reflex vagal inhibition also playing a role in the terminal episode [61]. As all of these disorders need to be carefully checked for, an autopsy approach to these cases has been delineated [52]. CT scanning can be useful in determining the level of airway obstruction prior to formal autopsy dissection [62].

In cases where hot food has been ingested acute edema around the glottis may obstruct the airways. In addition, food may impact more distally, for example in the duodenum causing lethal obstruction [63, 64]. Ingested fish or chicken bones may erode through the wall of the esophagus causing lethal aortoesophageal or carotidesophageal fistulas [61, 65]. Rarely, ingested bones may perforate more distally through the stomach or duodenum causing localized abscess formation with death from sepsis/multiorgan failure [66].

Miscellaneous

Overindulgence in food may result in unfortunate outcomes. For example, Boerhaave syndrome refers to spontaneous rupture of the esophagus from vomiting, often due to excessive intake of food and /or alcohol. The mortality rate is 20 to 40% [67, 68]. Ingestion of large meals in patients with anorexia nervosa has resulted in acute gastric necrosis, as has psychogenic polyphagia and bulimia [69, 70]. Prader-Willi syndrome, which is characterized by excessive appetite and the consumption of large amounts of food, has been associated with death from acute gastric distension with necrosis and overwhelming sepsis [71]. Malposition of the stomach with volvulus may be an additional complicating factor in individuals with cerebral palsy [72].

The issue of general overconsumption of calories in combination with physical inactivity has resulted in the so-called obesity epidemic with the mean adult body mass index (BMI) increasing by 0.4 kg/m^2/decade between 1980 and 2008 in 199 countries [73]. Obesity causes metabolic derangements that increase the rate of malignancies such as leukemia, lymphomas, melanomas, multiple myeloma, and carcinomas of the breast, endometrium, gallbladder, thyroid, prostate, esophagus, stomach, and colon. As well there is an increased incidence in the occurrence of premature death due to pulmonary thromboembolism, ischemic heart disease, cardiomegaly, sepsis and diabetes mellitus [73].

Very rarely food substances may be consumed during suicide attempts. The case of fish anaphylaxis was described

above [45] and two cases have also been reported from Japan of deaths due to hypernatremia following the ingestion of large amounts of soy sauce [74, 75].

Finally, the ingestion of non-food materials may also lead to lethal outcomes. Pica refers to the persistent eating of non-nutritive substances, such as soil, over time. This may cause death from airway obstruction, intestinal obstruction and perforation with peritonitis and generalized sepsis [76]. Individuals with Rapunzel syndrome from compulsive eating of hair (trichophagia) have trichobezoars extending from the stomach to the small intestine that may be associated with gastric perforation and death [77, 78]. The ingestion of other foreign material is usually only seen in individuals with mental impairment or psychiatric conditions. Death may result from acute upper airway obstruction or intestinal perforation with sepsis [79].

Conclusion

The cases described above demonstrate the importance of food-related deaths in terms of global mortality and the wide variety of lethal mechanism that may be involved. Autopsies need to be comprehensive with full ancillary testing, including particularly microbiology, looking for a range of potential pathogens. Medicolegal matters may be complex including issues around exposure to infectious agents, types of foods consumed, content and components of food, toxicological analyses, and duty of care.

Compliance with ethical standards

Ethical approval This article does not contain any studies with human participants performed by any of the authors. Approval to report the case was given by Forensic Science SA, Adelaide Australia.

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Conflict of interest The authors declare that they have no conflict of interest.

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