Salmonellosis is a communicable disease usually transmitted from vertebrate animals to man in food or drink; its world-wide prevalence has shown a dramatic increase in man and in animals during the past two decades. Nearly all the 800 types of Salmonelae so far discovered have been recovered from the intestinal contents of animal hosts; these bowel contents readily infect other animals or contaminate the environment. The cycle of infection involves the transfer of viable Salmonelae from one host to another: directly, when one host ingests the feces of another; indirectly, when the victim ingests contaminated material. Man may become infected at any stage of this natural cycle and may, himself, act as a reservoir of infection. Feces from infected animals and man readily contaminate human food, animal feed, rivers, water supplies, sewage and soil, any of which may act as vehicles of infection. Because of its universal incidence, its diverse manifestations and its complex epidemiology, salmonellosis now constitutes a serious threat to the health of man and animals (12, 80).

Twenty-five years ago typhoid fever caused by Salmonella typhi was a common and frequently fatal disease; food poisoning caused by other Salmonelae was relatively uncommon. The steady decline in the incidence of typhoid fever contrasts sharply with the marked increase in the incidence of salmonellosis. To illustrate, the annual reported incidence of typhoid fever in the United States decreased from 3,268 cases in 1946 to 608 cases in 1962; concurrently, the annual reported incidence of infections with other Salmonelae increased thirteenfold from 723 cases in 1946 to 9,680 cases in 1962. In this 17-year period about 32,000 cases of typhoid fever were reported, compared with over 75,000 cases of salmonellosis (Table 1).

The remarkable improvement in the typhoid picture has been attributed to: (a) more adequate investigation and reporting; (b) better methods for laboratory diagnosis; (c) better general hygiene and sanitation; (d) more widespread use of pasteurized milk and chlorinated water; (e) prophylactic immunization with T.A.B. vaccine; and (f) more thorough tracing of typhoid carriers. However, these measures, highly effective in reducing the incidence of typhoid fever, have completely failed to influence the incidence of salmonellosis (12).

The many factors responsible for the increase in the occurrence of salmonella incidents, particularly

<table>
<thead>
<tr>
<th>Year</th>
<th>Typhoid Fever</th>
<th>Salmonellosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td>3,268</td>
<td>723</td>
</tr>
<tr>
<td>1947</td>
<td>3,075</td>
<td>951</td>
</tr>
<tr>
<td>1948</td>
<td>2,840</td>
<td>882</td>
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<td>1949</td>
<td>2,795</td>
<td>1,243</td>
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<td>1950</td>
<td>2,484</td>
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<td>1952</td>
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<td>1955</td>
<td>1,704</td>
<td>5,447</td>
</tr>
<tr>
<td>1956</td>
<td>1,700</td>
<td>6,704</td>
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<td>1957</td>
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<td>6,693</td>
</tr>
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<td>6,363</td>
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<td>1959</td>
<td>859</td>
<td>6,606</td>
</tr>
<tr>
<td>1960</td>
<td>816</td>
<td>6,929</td>
</tr>
<tr>
<td>1961</td>
<td>814</td>
<td>8,542</td>
</tr>
<tr>
<td>1962</td>
<td>608</td>
<td>9,680</td>
</tr>
<tr>
<td>Total</td>
<td>32,127</td>
<td>75,646</td>
</tr>
</tbody>
</table>
and may develop symptoms. Because introduced such as canned meat and desiccated coconut Salmonella food. As very small numbers of typhoid bacilli are feces or either waterborne or milkborne, in recent years the classical outbreak of typhoid fever was local and the chronic human carrier who excretes bacterial multiplication in the vehicle. Although typhi in food.

The common paratyphoid organism in North America is S. paratyphi B. Its only permanent reservoir is man; domestic animals are occasionally infected and may develop symptoms. Because large doses of paratyphoid bacilli are necessary to initiate infection, food is the usual vehicle. Savage (75) found that 32 (80%) of 40 outbreaks reported in Britain between 1923 and 1941 were foodborne. The common foods were milk and milk products (13 outbreaks), synthetic cream (9 outbreaks) and confectionery (7 outbreaks); water was implicated only once.

'Food poisoning' Salmonellae in food.

The reservoirs of Salmonellae, other than S. typhi and S. paratyphi, are animals. The vehicles of infection are foods derived from animals, especially meat, eggs and milk which when contaminated and stored at room temperature encourage bacterial multiplication. The most prevalent organism in most countries is S. typhimurium. S. heidelberg, unknown in Canada before 1952, is now second only to S. typhimurium as a cause of human salmonellosis. Other common endemic types are S. thompson, S. newport, S. oranienburg, S. tennessee and S. montevideo.

'Animal' Salmonellae in food.

S. pullorum and S. gallinarum, causing pullorum disease and fowl typhoid in poultry, are relatively host-specific but may be recovered from food and occasionally cause disease in man. S. choleraesuis is common in pigs and may be transmitted to man in pork products, causing serious focal lesions or septicemia.

ANIMAL RESERVOIRS

The most important reservoirs of human salmonellosis are livestock and poultry. Salmonellae are common in pigs and poultry; they are frequent in rodents, not uncommon in cattle, sporadic in sheep and horses, and occasional in various wild mammals, birds and reptiles (46). These organisms are carried in the intestines and, occasionally, in the tissues of substantial percentages of apparently healthy livestock and poultry destined for human consumption, as well as of rodents and of household pets which mingle with farm animals and their future consumers (22). Surveys conducted in the United States have revealed a widespread distribution of Salmonellae. From 47 animal species Edwards et al. (24) isolated 111 different types, 61 of which were also recovered from man; these 61 types were responsible for 93% of human infections.

Moran (57) analyzed the types and distribution of 5,000 cultures of Salmonella (excluding the avian species S. pullorum and S. gallinarum) recovered from animals between 1957 and 1961; there were 84 different types from 35 animal species. The most common types were S. typhimurium (28%); S. choleraesuis (8%); S. anatum and S. heidelberg (each 6%);
S. enteritidis, S. newport and S. san diego (each 5%); S. infantis (4%); S. chester and S. saint paul (each 3%); and S. blockley, S. derby and S. munchen (each 2%). These 13 types accounted for 78% of the animal isolations.

Fifty-five different types were isolated from turkeys, 50 from chickens, 35 from cattle, 25 from pigs and 23 from dogs. Other species yielding Salmonellae included guinea pig, rabbit, squirrel, fox, nutria, chinchilla, skunk, opossum, elephant, rhinoceros, kangaroo, gorilla, loris, sloth, seal, reptile and fish. The animal sources of S. typhimurium indicate the wide dispersal of this pathogen in nature. S. typhimurium was recovered from 612 turkeys, 282 chickens, 67 skunk, 1 opossum and 1 reptile.

An anonymous ditty that appeared in the Lancet some years ago illustrates the ubiquity of this pathogen:

"An infection in beavers was transmitted to retrievers, And carelessly contracted by a vet.,
While the organism injected in a toad in Timbuctoo Was recovered from a tadpole in Tibet."

Salmonellae in livestock and abattoirs.

Pigs. Of the domestic animals commonly slaughtered for human consumption, pigs are most frequently infected with Salmonellae. Pigs are an important reservoir not only of the relatively host-specific S. choleraesuis and the universal, multi-host S. typhimurium, but also of S. senftenberg, S. bredeney, S. enteritidis, S. anatum, S. derby, and S. newport, the particular type depending on the locality.

In Florida, Galton et al. (32) found that 27 (7%) rectal swabs from 374 pigs on 11 of 28 farms yielded Salmonellae. To determine the distribution of Salmonellae, swabs were collected from pigs in transit between farm and consumer. Of 189 specimens collected at the lairages 148 (78%) yielded Salmonellae. Twelve (75%) of 16 samples of drinking water were positive. In uncemented lairages the soil was also contaminated. Swabs from 100 live pigs in lairages yielded 25 positives. Swabs from 98 pigs on the killing floor yielded 51 positives. Rectal and cecal swabs collected from 89 slaughtered animals yielded 17 (19%) rectal and 71 (80%) cecal positives. Rectal swabs were also collected just before evisceration. In the abattoir a total of 1,883 postmortem swabs yielded 966 (51%) positives. Swabs from the dehairing machine yielded 20% to 65% positives; swabs from the evisceration area yielded 74% positives; swabs from the cutting room and sausage room yielded 36% positives; and swabs from tables, knives and equipment yielded 25% to 43% positives.

In 1961 and 1962 Shotts et al. (78) surveyed abattoirs in Kentucky and recovered Salmonellae from 95 (54%) of 176 samples. The contaminated areas included mud in the lairage, the ramp to the kill room, the dehairing machine and chute, the scraping table, the hand saw and the edible viscera pan. Before operations began, 34% of the samples were positive, indicating inadequate cleaning and consequent carry-over of Salmonellae from the previous day. After operations were completed but before clean-up, Salmonellae were found in 28 (58%) of 48 samples. Rectal swabs were cultured from the same pigs at the sale barn, on arrival at the abattoir and after slaughter. Salmonellae were isolated from 9% of swabs at the barn, 26% at the abattoir and 80% after slaughter.

A small proportion of pigs on the farm are asymptomatic carriers of Salmonellae. When these infected pigs are herded together with healthy pigs during transportation, at the local market, in the lairages or holding pens, and in the abattoir itself, Salmonellae are readily disseminated directly from pig to pig by fecal contamination or indirectly through widespread contamination of the environment. The extent of this contamination in the lairage and abattoir depends on the local conditions, on the number of animals handled by the abattoir and on the length of time animals are held in lairages. Under unhygienic conditions there is a very real danger of serious spread of infection with the possibility of surface contamination of carcasses and widespread distribution of contaminated meat (52).

Cattle. Among large meat animals cattle are the second most common reservoir of Salmonellae. The types most often recovered are S. typhimurium and S. dublin. Recent reports indicate that salmonellosis among dairy and beef cattle is becoming a major problem. During 1959 and 1960 Ellis (25) reported in Florida 40 isolations of Salmonellae from cattle with enteritis, many of which continued to excrete Salmonellae indefinitely. When subjected to the stress of clipping, branding or undue exposure during shipping, many such carriers develop acute salmonellosis which may prove fatal.

Anderson et al. (2) studied the effect of transportation and holding on the incidence of salmonella infection in calves taken to abattoirs in England. As with pigs, infection rates increased between the farm and the abattoir. The mean infection rate in calves on the farm was 0.5%, rising to 35.6% in calves slaughtered two to five days after entering the lairage at the abattoir.

Salmonellae in poultry and processing plants.

Salmonellae are frequently recovered from the intestinal tract of fowl at necropsy and most flocks are exposed to these organisms at some stage of their
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Salmonellosis in chickens may cause mortality rates of up to 80% in the first 2 or 3 weeks of life; survivors may serve as intestinal carriers for long periods (85). Adult birds exposed to infection may harbor organisms indefinitely without exhibiting symptoms.

In a survey of American processing plants, Galtou et al. (31) found Salmonellae in 11% of 118 swabs from tubs holding iced birds; these organisms were also recovered from swabs from the sides of 3% of 292 birds. At a new English plant processing 12,000 broiler chickens daily (20, 21), Salmonellae were isolated from 75 (14%) of 544 specimens. Eight different Salmonellae were isolated, S. typhimurium on 17 occasions and S. thompson on 11. On 13 of 23 weekly visits to the plant Salmonellae were isolated from eviscerated carcasses and from water tanks in which carcasses were cooled. Almost 10% of eviscerated carcasses and edible viscera harbored Salmonellae; there was therefore ample opportunity for widespread contamination.

FOOD VEHICLES

The most important vehicle of Salmonellae is human or animal food (Figure 1) (8). The responsible foods are either derived from intravitally infected animals (endogenous) or they are exposed to contamination by infected animals, infected persons or contaminated objects during preparation or storage (exogenous) (16). The foods most commonly contaminated with Salmonellae include (1, 28): (a) meat (including poultry) and meat products such as meat pies, brawn, pressed beef, sausages, cold cooked meats, rebated meat and gravies; (b) eggs and egg products such as duck eggs, dried egg powder, egg albumen, frozen egg and synthetic cream, often prepared from frozen egg; (c) milk and milk products such as ice-cream, cream, custard filled confectionery, salad creams and trifles; (d) fish such as made-up fish dishes and shellfish especially oysters from uncontrolled beds; and (e) canned foods such as meats. The most vulnerable foods are those which are lightly cooked and subject to much handling. Once contaminated, such foods favor the multiplication of bacteria. The number of Salmonellae present in a food depends on the nature of the food and the temperature and time of storage. All the common vehicles are produced in bulk, which probably accounts for their high rate of contamination. The appearance, smell and taste of food contaminated with Salmonellae are usually unaltered (38).

The known ways in which food may become contaminated with Salmonellae are (19): (a) by intravitall infection of poultry and livestock resulting in sick animals or asymptomatic carriers; (b) by failure to pasteurize milk from infected cows; (c) by infection of eggs in the oviduct or by contamination of eggs by feces; (d) by use of contaminated egg products in processed foods; (e) by food preparation in an already contaminated area; (f) by contamination with feces from infected rodents; (g) by contamination with organisms from flies and other arthropods; and (h) by human excreters—cases, convalecents or asymptomatic carriers.

Statistics of the prevalence of salmonellosis in the United States are based on the number of foodborne and waterborne disease outbreaks reported to the United States Public Health Service. In Table 2 the reported occurrences of typhoid fever, by outbreaks and cases, is compared with that of salmonellosis for the 5-year period 1956 to 1960 (17). The disparity in the figures presented in Tables 1 and 2 is difficult to explain; it is probably due to failure to report outbreaks and to the prevalence of sporadic cases. By contrast, statistics of the prevalence of salmonella infection in England and Wales (where more comprehensive records are maintained) are based on the number of food poisoning incidents reported to the Ministry of Health and to the Public Health Laboratory Service. Table 3 compares the reported occurrences of food poisoning incidents, by presumed causes, in the same 5-year period. Food poisoning incidents comprise general outbreaks (two
isolated Salmonellae from 17% of raw poultry samples, from 4% of raw pork products, from 3% of lamb samples, and from 1% of beef samples. The isolation rate from healthy pigs was 0.4% at the time of slaughter, but rose to 4.9% in sausages prepared from the same carcasses. The contamination rate was 4% in carcass meat and 10% in boned-out meat (41). In Northern Ireland Newell et al. (63) found Salmonellae in 3% of pork samples and in 70% of pork sausage samples. In England Hobbs and Wilson (41) regularly isolated Salmonellae from 3% to 4% of sausage samples. The salmonella recovery rate was 5% for manufactured bulk sausages and 11% for bulk sausages prepared in the retail market (88). Processed fresh meat, such as minced meat, boned-out meat and sausages, is liable to contamination during processing as the carcass of a single infected animal may contaminate the whole environment which may in turn contaminate subsequent batches of meat, unless plant sanitation is exceptionally thorough (52). Contaminated raw meat may be responsible for the transfer of Salmonellae to the environment of the butchers’ shops, to kitchens, to a variety of cooked products and to hands. Food handlers may ingest small doses of Salmonellae and become asymptomatic carriers liable to contaminate any food they handle.

A variety of meatborne outbreaks are summarized to illustrate some of the links in the chain of infection due to contaminated meat and meat products.

**Fresh meat outbreak.** Meat was the probable vehicle in this smoldering outbreak that lasted for 6 months. In Wales 105 widely scattered incidents were due to S. typhimurium. This agent was isolated in a neighbouring abattoir from 14 floor drains, from 6 samples of human sewage and from 1 rat. The same phage-type had been isolated from livestock on 3 farms in the previous year. Feces were therefore collected from 201 cattle and 69 pigs: all the cattle were negative, only one pig was positive. Of 54 local food establishments examined by the drain swab technique (35, 56) 13 butchers’ shops and 2 bakerhouses yielded this organism. At another butcher’s shop one employee, who was also an apprentice slaughterman at the abattoir, was positive (36).

**Ham outbreak.** Smoked ham was the vehicle in a family outbreak due to S. infantis. Eight persons fell ill after eating raw or lightly fried slices of ham. Culture of the ham revealed the presence of 23,000 organisms per gm. Inadequate refrigeration and cooking were responsible for this incident (3).

**Turkey outbreaks.** Turkey meat was the suspected vehicle in two explosive outbreaks of salmonella gastroenteritis in British Columbia in 1960 and 1962. The first incident was due to infection with S. heidelberg and S. thompson, both of which were recovered from turkey stuffing (6). The second incident was due to S. heidelberg. No food remnants were available for culture, but the same salmonella type was recovered from abdominal swabbing of 1 of 4 turkeys from the same batch (7).

**Roast turkey outbreak.** The vehicle again proved to be turkey in an outbreak due to S. typhimurium involving 300 inmates of a penal institution. Cold roast turkey was sliced on the same chopping block used for preparing the uncooked

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**TABLE 3. FOOD POISONING INCIDENTS REPORTED IN ENGLAND AND WALES GENERAL OUTBREAKS, FAMILY OUTBREAKS, AND SPORADIC CASES FROM 1956 TO 1960, BY PRESUMED CAUSES**

<table>
<thead>
<tr>
<th></th>
<th>General outbreaks</th>
<th>Family outbreaks</th>
<th>Sporadic cases</th>
<th>All incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonella</td>
<td>465</td>
<td>1,762</td>
<td>20,147</td>
<td>22,374</td>
</tr>
<tr>
<td>Staphylococcus</td>
<td>203</td>
<td>146</td>
<td>251</td>
<td>600</td>
</tr>
<tr>
<td>Other organisms</td>
<td>374</td>
<td>64</td>
<td>53</td>
<td>491*</td>
</tr>
<tr>
<td>Not discovered</td>
<td>832</td>
<td>1,027</td>
<td>11,029</td>
<td>12,888</td>
</tr>
<tr>
<td>All agents</td>
<td>1,874</td>
<td>2,999</td>
<td>31,480</td>
<td>36,352</td>
</tr>
</tbody>
</table>

*excluding chemical.

*includes 465 C.L. perfringens.

—or more cases or excreters from different families), family outbreaks (two or more cases or excreters from the same family), and unassociated sporadic cases or excreters (12).

In England and Wales between 1949 and 1960 there were just over 3,100 general and family outbreaks (28% of the total) in which there was reasonable certainty that the food vehicle had been identified. Of these outbreaks, 73% were associated with meat; 8% with sweetmeats; 6% with fish; 6% with egg and egg products; 3% with milk and milk products; 2% with vegetables; 1% with fruit; and 1% with other foods (12).

**Meat and meat products.**

Of the outbreaks in England and Wales associated with meat, less than 2% were caused by fresh meat; 86% by “processed and made-up” meat; 8% by canned meat; and 4% by “meat” with no further description. Freshly cooked meat is clearly much safer than processed meat.

The degree of contamination of fresh meat depends on the type of product. Wilson et al. (88)
Eggs and egg products.

Salmonellae readily gain access to bulk egg products when eggs are broken out commercially (16, 80). As these commercial products are used in the mass production of many foods eaten without adequate cooking, they represent a serious health hazard (39, 68).

During World War II, Salmonellae were isolated from approximately 10% of samples of spray-dried egg imported into Britain from the United States, Canada and the Argentine. Of the 33 types isolated 22 were new to Britain. Because the number of Salmonellae never exceeded 30 per g, unrestricted distribution of this product was permitted (54). After the War 1.2% of English egg products from small packing plants yielded Salmonellae, while 2.6% of samples from large English frozen egg plants (70) and 7% of imported frozen egg samples were positive (68). Between 1955 and 1958 approximately 382 tons of dried egg products and 3,000 tons of frozen liquid egg were imported by the Port of Liverpool. Salmonellae were recovered from 13% of dried egg and 27% of liquid frozen egg samples (94). The salmonella contamination rate of imported bulk egg products in 1961 was: frozen whole egg, 16%; frozen white, 6%; dried white flakes, 13%; dried whole egg, 12%; dried white powder, 8%; and dried yolk, 5% (86).

The role played by egg-containing cake mixes in the transmission of salmonellosis in Canada is illustrated by two recent outbreaks. In Newfoundland, S. thompson was recovered from 29 persons and from six commercial cake mixes (9). In Saskatchewan a second outbreak was traced to contaminated cake mix (79). Seven of the 22 men at a camp became ill following the consumption of angel food cake contaminated with S. thompson and S. heidelberg. S. thompson was recovered from the seven victims and from baked angel food cake similar to that consumed by them. S. thompson and S. heidelberg were isolated from two cake mixes. An additional danger of such contamination lies in the dissemination of contaminated powder in stores, in kitchens and in the home. To discover the extent of the problem, a survey of commercial egg products was undertaken in Canada: 21% of 114 samples of frozen egg products and 54% of 119 samples of cake mix yielded Salmonellae (83). Accordingly, the Canadian Department of National Health and Welfare introduced a new regulation making it an offence to sell egg products that contain Salmonellae. The immediate effect of this regulation was encouraging: the contamination rate of egg products was reduced from 38% to 2% (81, 82).

Fresh shell eggs from hens are rarely responsible for human salmonellosis, but raw or undercooked duck eggs are a common vehicle of infection. Egg-nog prepared from fresh duck eggs was the vehicle of infection in a large outbreak that affected 104 of 1,650 patients in a mental hospital in Massachusetts. S. typhimurium was isolated from the patients and from 3 duck eggs from the neighbouring farm; 5 of 27 birds yielded this agent at necropsy (86). Raw or undercooked eggs were responsible for an interstate outbreak of hospital-associated infections. Between March and August, 1963, 825 isolations of S. derby were made from patients and staff of 33 hospitals in 13 states. This agent was also recovered from 4 of 42 slurries (15 to 18 whole eggs per slurry) of

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birds. The agent was recovered from more than 100 of the patients and from raw frozen turkey necks (30).

Roast pork and turkey sandwich outbreak. Two cooked meats were the probable vehicles of infection in an extensive outbreak of gastroenteritis on board a ship. The outbreak occurred in 2 phases. In phase 1, turkeys, presumably contaminated with S. chester, were removed from frozen storage and allowed to thaw on a table. During the thawing process, roast pork was carved on a cutting board adjacent to the turkeys. It was presumed that juice from the thawing turkeys contaminated the cutting board with S. chester and that the roast pork acted as the vehicle of infection. In phase 2, the same cutting board was used, presumably without adequate cleaning, to slice left-over turkey for sandwiches, the presumed vehicle in phase 2 (72).

Chicken salad sandwich outbreak. Home-made chicken salad sandwiches were responsible for causing typhoid fever in 31 of 88 persons who attended a wedding reception. One of the women who prepared the sandwiches was a typhoid carrier excreting organisms of the same phage-type as those recovered from the victims (11).

Cooked meat outbreak. The food implicated in this outbreak of typhoid fever was cooked meals served at a restaurant in Alaska and in an aircraft bound for Seattle. There were 3 local cases, and 4 passengers subsequently fell ill, 1 in Alaska, 2 in Washington and 1 in California. The meals had been prepared by an itinerant cook who proved to be a typhoid carrier. This is an excellent example of the part played by air transportation in the dispersal of persons already exposed to infection (87).

Meat pies outbreak. Meat pies eaten without further heating were the cause of an epidemic affecting 50 persons in 11 families and one group of boys. Salmonellae were recovered from the stools of patients and asymptomatic carriers and from 13 meat pies. A dog developed gastroenteritis after eating one of the pies. At the bakery, pastry blocks were hand-filled with prepared meat by 3 cooks. The pies were baked for 25 to 30 minutes at 332 to 246°C. Warm gelatin was added after baking. Salmonellae were recovered from the stool of one cook. The source of infection was either the meat or the infected cook (38).

Potted meat outbreaks. Sandwiches containing potted meat, reconstituted dried egg or meat extract were the vehicle of an outbreak that affected the residents of a hostel. The sandwiches, prepared in the afternoon by a woman with diarrhea for 5 days, were eaten for lunch the following day after storage at room temperature. S. typhimurium was recovered from the woman, from 75 men who had eaten sandwiches, from 4 other residents who probably ate sandwiches, from meat extract and from one trapped mouse. The 3 predisposing factors in this outbreak were the presence of infected rodents in the hostel, the presence of a food handler with salmonellosis and exposure of a suitable food vehicle to conditions of time and temperature conducive to bacterial growth (28).

Poultry feed, duck and prepared meat outbreak. Prepared meat was the vehicle in this outbreak involving 20 persons due to S. saint paul. The epidemiology was complex. Farm ducks in England became asymptomatic carriers of this organism after eating contaminated meat meal imported from America. After slaughter these ducks were eviscerated in the room of a butcher's shop where cooked meats were prepared. Fecal material from the ducks was inadvertently transferred to the cooked meat being prepared for sale. The meat was purchased by a number of families and eaten without further cooking (30).
cracked eggs and from one sample of poultry feed. No Salmonellae were recovered from intact eggs. In this epidemic extensive secondary spread of infection, presumably from person to person, became the major problem (73). Queen's pudding made of egg yolk, milk, breadcrumbs and egg white was responsible for an outbreak involving 130 patients and staff in an English hospital in 1949. The yolks of 200 duck eggs were lightly cooked and the whites were merely browned. All who ate the pudding were ill. Duck eggs should always be adequately cooked; this involves boiling for 15 minutes or frying on both sides (38).

Frozen egg is a common source of S. paratyphi B (62). This product is one of the constituents of synthetic cream widely used in the manufacture of confectionery. Four outbreaks of paratyphoid fever in the United Kingdom between January and May, 1963, involving 250 human infections were traced to 3 shipments of frozen whole egg from China contaminated with S. paratyphi B. The responsible foods were cream trifles, cream cakes and chocolate eclairs. The association of bakery products with paratyphoid fever was first noted in World War II; it was later suggested that the organism was introduced into bakeries by some commonly used product (13). S. paratyphi B has been isolated from Chinese egg products in the United Kingdom every year since 1955 (77).

In a survey of an English bakehouse Salmonellae were isolated from 31 (28%) of 111 swabs from floor drains and from 15 (16%) of 93 swabs from staff toilets. Salmonellae were also recovered from the outflow water of staff wash basins and from swabs wiped over machinery, even after routine cleaning. Chinese frozen egg was in daily use and was visible on the floors and tables and on the hands and arms of bakery staff (35). Trifle including cake made with an egg product was responsible for an outbreak involving over 100 school children. S. typhimurium and S. thompson, both commonly found in egg products, were recovered from the patients, from the trifle, from stools of bakery personnel and from drain swabs (37).

Milk and milk products.

Milk and milk products caused only 3% of the general and family outbreaks in England and Wales between 1949 and 1960. Raw milk from a cow with mastitis was the vehicle of infection in a typical explosive outbreak comprising 77 cases and 46 asymptomatic carriers (47). S. heidelberg was isolated from the patients, from the udder of the cow at necropsy, from filters and churns at the farm, and from animal feed similar to that supplied to the farm (18). Only one case was reported after pasteurization was instituted (47). Raw milk was responsible for another outbreak due to S. heidelberg. The interesting feature of this epidemic was that raw cow's milk from herds yielding S. heidelberg and S. montevideo was being sold in vending machines. Of the 28 persons infected with S. heidelberg 20 drank milk from the vending machine, 4 acquired infection by family contact and 4 had no obvious mode of infection. Of the 2 persons infected with S. montevideo the father drank contaminated milk; two weeks later his 15-month old son acquired the infection probably by contact (43). Raw milk supplied to schools and the public also caused an explosive outbreak due to S. dublin affecting at least 610 people. This agent was isolated from all the patients with symptoms, from the milk, and from the udder and feces of the affected cow (50). Raw milk from a small dairy was also the vehicle responsible for at least 16 cases and 5 asymptomatic carriers. S. typhimurium was isolated from the patients, but not from the milk or milk handlers. Nevertheless, the circumstances surrounding the illness and death of one of the cows strongly suggested that the cow was the source of infection (85).

Pasteurized milk was the vehicle in an outbreak of paratyphoid B fever in South Wales. On inquiry it was found that polluted river water was used as the final rinse for milk bottles, after they had been cleaned and heat-treated. The rinse water was chlorinated, but not always adequately; consequently, paratyphoid organisms occasionally escaped destruction and were able to multiply in the pasteurized milk after the bottles were filled (84).

Fish.

Freshly cooked fish is rarely the vehicle of salmonella food poisoning, but processed fish products such as fish pies and fishcakes may readily be contaminated. Between 1919 and 1934 it was estimated that more than 100,000 cases of typhoid fever due to the consumption of shell-fish occurred in France: 25,000 were fatal (38). Fifteen types of Salmonellae were isolated from the intestinal contents of fresh fish sold in a fish market at Colombo, Ceylon: 39 fish of 24 species and 5 samples of fish-washings yielded Salmonellae (34).

Vegetables.

Vegetable products are rarely contaminated with Salmonellae; the only important exception is desiccated coconut (50). In 1953 an outbreak of typhoid fever and salmonellosis, associated with contaminated desiccated coconut, occurred in Australia. S. typhi, S. paratyphi B and 12 other salmonella types were isolated from samples of coconut imported from Papua. Salmonellae, including one strain of S. paratyphi B, were also isolated from Ceylonese coconut (48). In 1961 two packets of desiccated coconut purchased from a retail store in British Columbia both yielded Salmonellae on culture.

In 1959 and 1960 a bacteriological survey of desiccated coconut imported into England from Ceylon revealed that 9% of 851 samples contained Salmonellae. Of the 18 different types found, S. paratyphi B and S. bareilly were the most common (29). Contamination from man, animals or water probably occurred during manufacture. The chief hazards from contaminated coconut arise when it is used uncooked in foodstuffs which support the multiplication of Salmonellae, when it is eaten raw, and
when it cross-contaminates other foods in the kitchen or the bakehouse either directly or by way of utensils or hands.

Potato salad was the common vehicle of infection in an extensive outbreak of typhoid fever in an American youth camp in West Germany in 1958. The salad was prepared by a female civilian cook on the evening before it was to be eaten and left at room temperature. More than 400 persons consumed this salad and about 15% acquired typhoid fever.

Canned food.

Canned foods rarely transmit *Salmonella*, unless the contents are contaminated after the tin is opened. The standard of commercial canning is high; it is therefore unusual to discover under-processed cans or cans with structural defects. Occasionally cans are badly manufactured, but these are usually discovered by the manufacturer, the retailer or the health inspector. A contaminated can of ox-tongue was, however, responsible directly or indirectly for 33 cases in an English typhoid epidemic. The tongue had been cut up in a shop and the same knife had been used for slicing ham on the counter. The can had been processed in South America, but it had been cooled by immersion in heavily contaminated river water below the inflow of the town sewage (15).

It is rare to recover *Salmonella* from canned cream; there is on record in England one instance in which *S. typhi* was recovered from an ineffectively sealed can of cream. As there had been complaints of the odor of this product, nearly 1,000 cans of the same batch were examined bacteriologically: 17% were contaminated with spore-forming and non-spore-forming bacteria. The cans had been processed in Ireland and cooled in water from a well subject to fecal pollution. The batch was withdrawn from the market and no cases of typhoid fever resulted (74).

Cross-contamination of canned meat was the probable cause of infection in an English epidemic of salmonellosis involving 3,000 to 4,000 persons with 3 deaths. Portions of the carcass of an infected pig were distributed to several butchers' shops where they were handled in conjunction with canned meat. The infective raw meat and the cold cooked meats were weighed on the same balances, cut with the same knives and served by the same hands. The contaminated pressed beef and other cooked meats were eaten without further heat-treatment, often after storage at a temperature favourable for bacterial multiplication (10).

The excellent keeping quality of canned food is illustrated by the following anecdote. Two cans, one of carrots in gravy and one of roasted veal, which had formed part of the stores taken by Sir Edward Parry on his Third Expedition in search of the North West Passage in 1824, were opened and cultured in 1939, 115 years later. Both foods were appetizing; the carrots were sterile; only aerobic spore-bearers were grown from the veal (38).

Other foods.

In carrying out epidemiological studies on the spread of foodborne *Salmonella* it is a sound principle to investigate first those foods that are most readily contaminated by *Salmonella* and those foods which readily support the multiplication of pathogens. Such foods have already been discussed. The following foods rarely act as vehicles for *Salmonella*: jams, fruits, vegetables, pickles, sauces, dry powdered foods, bread and fats. Some do not support growth and multiplication of pathogenic bacteria; others may slowly destroy them. Jams contain too much sugar. Acid fruit dishes do not support growth, though the skins of fresh fruit and vegetables may transmit typhoid and paratyphoid bacteria. Freshly cooked vegetables may be eaten with safety. Pickles and sauces are too acid. Powdered foods are usually safe if kept dry, but cake mixes and other powder containing unpasteurized egg products are a major vehicle of infection. The unwrapped loaf of bread is not the potential vehicle of *Salmonella* that many suppose it to be. Fats do not encourage the growth of *Salmonella* (38).

Animal by-products.

In the past 5 years many surveys have been conducted to discover the prevalence of *Salmonella* in animal by-products and their importance as a source of salmonellosis in animals and, indirectly, in man. An English survey revealed *Salmonella* in a wide variety of products, including raw and processed materials, imported bones, bone products, fish meal, complete foods and fertilizers. Altogether 24% of 1,279 samples yielded 88 different types of *Salmonella* (69). In a further study of 4,140 samples *Salmonella* were present in 9% of raw ingredients, in 3% of finished meal and in 0.3% of pelleted food. The bacterial counts were low, usually less than 10 salmonellas per 100 g (71).

In the United States 59 types of *Salmonella* were demonstrated in 13% of 5,700 samples, including bone-meal, feather meal, fish meal, and complete feeds; in dog food, meat scraps and egg products (egg concentrate, frozen whites, dried whole eggs, frozen yolk and dried yolk), and in poultry by-products, poultry feed and tankage (59). In a Florida survey 14 feed samples were found to contain *Salmonella* (25). Similar results were obtained in Canada (44, 89). Dry rendered tankage samples yielded *Salmonella* in 18 (15%) of 78 samples and wet rendered tankage, bone, liver and lung, blood, feather and fish meals in 8 (8%) of 101 samples. Of particular
interest was the isolation of *Salmonellae* from 4 samples of meal after 12 months’ storage at 8°C, whereas no *Salmonellae* were recovered from portions of the same samples stored at room temperature for a similar period (89).

Many animal feeds are treated with heat at temperatures high enough to destroy *Salmonellae*; they may, however, be re-contaminated by dust or from containers (89). Such feed is a common source of infection and results in the asymptomatic carrier state. In this manner contaminated animal feed may be the primary source of infection in human outbreaks and sporadic cases (31, 32, 40, 63).

**Occupational hazards.**

Although it is often impossible to determine whether the infected food handler is the source of infection or the innocent victim, Galton and Steele (33) found that the carrier state occurred much more frequently in those who handled food than in the general population. Over 60% of salmonella cultures isolated from known human sources were derived from symptomless excreters many of whom were food handlers.

In an attempt to estimate the occupational hazard of food handling, Newell (61) interrogated food handlers and their families. He discovered that 80% of the indicator patients leading to households were children under 10 years of age; on further inquiry, he discovered that the fathers of 43% of these children were employed as food handlers. In a group of 100 men who handled contaminated fish meal only one gave a history of gastroenteritis in the previous month; nevertheless, 14 of these men reported diarrhea in their family contacts during the previous month. This suggests that the infected but asymptomatic handler of contaminated food may carry infection home to his family (61). Similarly, Edwards (23) considered the carrier state to be an occupational hazard to persons who handle uncooked meat and meat products. If asymptomatic carriers were regularly investigated epidemiologically, it is probable that an animal source of infection would often be disclosed (61).

**CONTROL AND PREVENTION**

There are thus many means whereby *Salmonellae* gain access to the food of man and his domestic animals. There is an obvious and urgent need for detailed study, in all parts of the world, of the transmission of salmonellosis with the object of breaking the links in this complex chain of infection. This can only be achieved if epidemiologists, bacteriologists and clinicians, both medical and veterinary, work in close co-operation and follow-up the epidemiological leads in every salmonella incident. As new means of transmission are disclosed and proved, regulations for control should be introduced. In this connection the food industry is faced with a major task in the production and distribution of clean, safe food. In his review of the health problems of this industry, Thatcher (82) concluded that distribution of new forms of food, such as frozen foods, without adequate bacteriological control was hazardous. Industry should therefore be encouraged to set up laboratory facilities to ensure the safety of their products, to assess the standard of sanitation in their plants and to determine possible avenues of contamination (51).

Ideally, only animals known to be free from *Salmonellae* should be used for the production of human and animal food. Moreover, food must be protected at all stages of production, distribution and consumption from the farm to the table. This is no easy matter as problems arise with intravitally infected or contaminated raw materials; with processing, manufacturing and packaging; and with distribution, marketing and consumption. The aim is to raise salmonella-free animals in a salmonella-free environment on salmonella-free diet and, thereby, to ensure that human food is salmonella-free. To achieve this ideal, concerted action at the local, state, national and international level is required of all those agencies, official and commercial, responsible for the health and feeding of man and his food animals (8).

As a first step in the war on salmonellosis the basic principles of food hygiene for the control of this communicable disease should be rigorously instituted at all stages in the food production line from farm to table. There are 4 general procedures or practices that should be followed in the handling of food (26): (a) introduction and maintenance of a high standard of hygiene; (b) minimal holding of food in the “incubation danger zone”; (c) universal use of low temperature storage; and (d) application of physical agents for the destruction of *Salmonellae*.

**Sanitation.**

A high standard of hygiene and sanitation is necessary to minimize the opportunities for contamination of the environment. All buildings used for housing or slaughtering animals and all rooms in food establishments should be planned so that good sanitary practices can be maintained. Infestation with rodents and insects should be prevented. Personnel should be taught to observe strict personal hygiene and to report illnesses promptly. Regular medical examinations of all food handlers have been advocated. Every endeavor must be made to prevent “seeding” of the environment with living *Salmonellae* liable to contaminate batches of food being processed and to infect employees. The food-han-
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Handling public should be educated by all available media in modern food hygiene practices. The housewife should appreciate the hazards of unhygienically handled food to the health of her family. Instructions for cooking and storing foods liable to contamination should be issued to the housewife at the retail store. Cleanliness in the plant and rapid handling of food are also important measures.

Incubation danger zone.

Holding temperatures that encourage growth of Salmonellae should be avoided, wherever possible. The temperature range which supports growth is 10 to 49 °C; this is the incubation danger zone. When food is exposed to temperatures within this range, the holding time must be kept to a minimum and in no case should it be allowed to exceed 4 hr.

Low temperature storage.

Storage at low temperatures whether by freezing or by refrigeration at 0 to 5 °C is effective in preventing growth of Salmonellae, but neither method has any appreciable effect on the viability of these organisms. Many outbreaks of foodborne salmonellosis occur in the warmer summer months when foods may be exposed to temperatures in the incubation danger zone for long periods. Adequate refrigeration facilities should be provided in all food-handling establishments including the home.

Prompt refrigeration of foods as soon as they are prepared and refrigeration of leftover foods will reduce the risk of outbreaks of food poisoning. Perishable foods must be kept as cool as possible during preparation. Under no circumstances should they be held at room temperature for more than the shortest time consistent with good handling procedures. Foods to be stored in the frozen state should be chilled or frozen rapidly so that the temperature at the center is reduced to 50 °C or lower within 4 hr.

Heat.

Salmonellae are susceptible to heat and radiation. Most Salmonellae are killed by exposure to a temperature of 55 °C for 1 hr or of 60 °C for 15 to 20 min (19); all are killed by exposure to the temperature effect of pasteurization (80).

Adequate cooking destroys Salmonellae. To be effective, however, temperatures of 74 to 77 °C must be reached in the center of the food during the cooking period. Although adequate cooking will kill vegetative organisms, it cannot be relied on to destroy any toxins that may be present. Leftover foods should be reheated to at least 74 °C as there is a danger of Salmonellae surviving in food subjected to irregular heat (55). Beloin and Schlosser (5) demonstrated experimentally that cakes containing dried egg contaminated with Salmonellae could be rendered safe by baking if the center reached a temperature of 71 °C or above. Murdock et al. (60) showed that Salmonellae were eliminated from liquid whole egg by pasteurization at temperatures of 64 to 65 °C for 2½ min. Angelotti et al. (4) studied the effects of time and temperature on the survival of Salmonellae in common perishable foods. Salmonellae multiplied in the 3 foods at temperatures between 7 and 46 °C. In custard they multiplied at a temperature of 45 °C but the numbers decreased at temperatures between 47 and 49 °C; in chicken à la king, they were killed at temperatures above 46 °C; in ham salad the numbers of organisms decreased at temperatures between 44 and 49 °C.

Radiation.

Salmonellae vary in their sensitivity to gamma radiation. Comer et al. (14) and Ley et al. (49) estimated the dosage required to eliminate Salmonellae from whole egg, frozen horsemeat and bone meal. At the recommended dosages the quality of these foods was unaffected.

Need for Action

These basic principles of food hygiene must be taught to all who are concerned with the provision of safe, clean food (1). There must be a greater awareness of the hazards inherent in the changing habits of human feeding, in the changing patterns of animal husbandry and processing, and in the increased distribution of foods susceptible to contamination. Much has already been done. In 1957, the International Association of Milk, Food and Environmental Sanitarians produced an excellent monograph entitled "Procedure for the investigation of foodborne disease outbreaks" (67). This is a standard work now widely used by epidemiologists throughout the world. In April, 1960, the Royal Society for the Promotion of Health, London, England, presented a symposium on Food Poisoning at their annual Health Congress (12, 80). Because of the increased prevalence of salmonellosis the Health Branch in British Columbia, Canada, introduced in August, 1961, a pilot study to determine the most important reservoirs and vehicles of human salmonellosis; a salmonella project was set up in April, 1962, and a salmonella Working Party established. The U. S. Livestock Association at its 65th annual meeting in Minneapolis, October to November, 1961, presented an extensive salmonella symposium. The U. S. Communicable Disease Center started a trial surveillance program for salmonellosis in April, 1962, and by January 1, 1963, a formal program was introduced with the cooperation of all 50 states, the District of Columbia and the Virgin Islands. In October, 1962, the Conference of Public Health Veterinarians, American Public Health Association, selected as their
discussion topic The Epidemiology of Salmonellosis. The World Health Organization and the Food and Agriculture Organization have shown considerable leadership in the field of food poisoning and have published comprehensive reports: European Technical Conference on Food-borne Infections and Intoxications (27), Joint WHO/FAO Expert Committee on Zoonoses Second Report (46) and Joint FAO/WHO Expert Committee on Meat Hygiene Second Report (45). In August, 1962, the Standing Committee on Food Microbiology and Hygiene of the International Association of Microbiological Societies (I.A.M.S.) met in Montreal, Canada, to discuss the Microbiology of Frozen Foods (81). The U. S. National Conference on Salmonellosis met at the Communicable Disease Center, Atlanta, Georgia, in March, 1964.

National and international interest in the salmonella problem is now focussed on methods for preventing the spread of salmonellosis which will achieve not merely its control but its ultimate eradication.

Water supplies and milk have been made safe by the efforts of health officers, bacteriologists and veterinarians. It is now time to pay more attention to bringing other foods up to the same high standards (12).

CONCLUSION

It would be appropriate to close in a lighter vein.

In these days of indigestion
It is oftentimes a question
As to what to eat and what to leave alone;
For each microbe and bacillus
Has a different way to kills us
And in time they always claim us for their own.
Some little bug is going to find you some day
Some little bug will creep behind you some day.

Let us therefore insist that all possible efforts are made to ensure that salmonellosis is controlled before the salmonella bug follows Roy Atwell's advice and creeps up behind us8.

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CLOSTRIDIUM BOTULINUM FOOD POISONING1, 2

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SUMMARY

The outbreaks of botulism in the United States during 1963 stimulated renewed interest in this food-borne disease, primarily because commercially prepared foods were involved. Three of the outbreaks were caused by Clostridium botulinum type E in fishery products. Two of these resulted from the consumption of smoked fish from the Great Lakes.

A survey has been started to see if C. botulinum type E is common on fish from the Great Lakes. Toxin neutralization tests have shown the organism to be present in cultures from nine of ten locations sampled in Lake Michigan. The organism was found more frequently in the intestinal tract than on gills, livers or the external surfaces of the fish. Over 75% of the cultures prepared from the intestines of fish caught in one large bay of Lake Michigan proved to contain type E toxin. The incidence of the organism in fish from the main body of the lake has been much lower than this.

The first recognized outbreak of botulism was observed over 200 years ago (10), although the causal organism was not isolated until 1805 (9). The disease is caused exclusively by the ingestion of food in which Clostridium botulinum has grown and produced its toxin.

According to Lamanna (18), botulinum toxin is the most potent poison known to man. Less than 1 x 10^{-10} gram will kill a mouse. Although the toxin is a protein and therefore a large molecule, it somehow passes into the lymphatic system from the upper part of the intestinal tract (18). By means that are not yet understood, the toxin acts on certain myoneural junctions, interfering with the release of acetylcholine and thus preventing the passage of nerve impulses. The muscles involved in respiration are particularly affected, and death results from asphyxiation.

Gastric symptoms frequently are the first sign of botulism, with nausea and vomiting often appearing in 12 to 18 hr. Patients may complain of a dry mouth during this time. Neurologic symptoms soon develop, with double vision, muscular weakness, and difficulty in talking and swallowing. Respiratory paralysis follows, with death in fatal cases usually coming in three to six days. Complete recovery in non-fatal cases may require several months (4, 5, 26).

Botulism is a disease of both man and animals. Reports of human botulism have come mainly from North America, Europe and Japan, although two outbreaks have been recorded in Argentina and two in Australia (19). The true incidence is unknown because of frequent failure to recognize the disease. In the United States there are usually no more than

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2Presented at the 51st Annual Meeting of the International Association of Milk, Food and Environmental Sanitarians, Inc., at Portland, Oregon, August 18-21, 1964.