Bacterial challenges in food

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Summary

Qualitative and quantitative aspects of bacterial challenges that might be encountered in food are discussed with reference to recognized and relatively unrecognized hazards. Mechanisms of pathogenicity are reviewed and the populations at risk are noted. The bacterial content of food as it is served at table merits more study. The challenge of prevention by education is discussed. Indirect bacterial challenges in our food are considered. The real challenge of diagnosis depends upon an awareness of a complex range of conditions; the importance of effective communication with efficient laboratory and epidemiological services is stressed. There is an increasing need for care in the preparation and distribution of food.

Components of pathogenicity

The various components involved in the expression of bacterial pathogenicity were summarized by Stanier, Doudoroff and Adelberg (1958) as follows. The source of the infectious agent may be a case of the disease or a carrier; a human or an animal source is usually incriminated. There is then a stage of transmission of the infectious challenge when an opportunity allows transfer to a new host, followed

by a process during which the infectivity of the agent may be established. Thereafter, the organism expresses its virulence and damages the host by essentially invasive or toxic mechanisms or a combination of these (Fig. 1).

The above concepts are changing, but they can be applied in various degrees to the food-borne diseases caused by bacteria. The outcome of such an attack on a new host depends upon many variables that may influence the host-parasite association and these include the nature and size of the challenge dose. It is useful to consider qualitative and quantitative aspects of the bacterial challenges that may be delivered in our food, and it is convenient to include milk and water in this consideration.

Measurement of challenge doses

In experimental work, infective hazards are considered in relation to the size of the challenge dose that may produce some demonstrable effect. A simple example, at least in theory, is the minimum lethal dose (MLD) for a specified test animal. In practice, as animal and human responses to infective or toxic challenges vary so much among individuals, the MLD is not a reliable measurement. It is better

FIG. 1. The 'components' of microbial pathogenicity.

to work in terms of the LD_{50} —the dose that is lethal for 50% of a test group of similar animals. If the standard indicating effect is not death but some other result, we work in terms of the effective dose (ED) and the ED_{50} . The ID_{50} is similarly used if infectivity is measured. There is no need to be restricted to 50% in these measurements; the ED_{75} or the ED_{35} might be of interest. However, it is well known that dose-response curves tend to be linear in their mid-section and are far from linear at the extremes where individual variation is so obvious. In experimental work, therefore, we are seldom concerned with the ED_1 —the effective dose for 1% of the test group; and we are even less concerned with the dose that might affect 0.01% of the test group.

On the other hand, those who are responsible for the production and distribution of our processed foods realize that they have in Britain a potential test group of 50 million individuals. An ED_1 challenge in a widely distributed food under these circumstances would be catastrophic. Moreover, a human population is in no way composed of similar individuals. Susceptibility to various bacterial challenges in such a group varies enormously, and there are innumerable permutations of circumstances that might influence the challenges and those challenged. It is therefore clear that a food manufacturer must take into account and make some allowances for: (1) unfavourable situations that may adversely affect his product; and (2) unduly susceptible members of the public, for example those at extremes of age or convalescent patients, who may be more severely challenged by the bacterial content of his products.

Infections associated with a low challenge dose

A few organisms have specific infective potential at relatively low challenge doses and these are perhaps passively carried on hands or in food or drink to produce new cases. Such infective hazards include typhoid fever and *Escherichia coli* gastro-enteritis. We are still uncertain regarding the infective doses of the respective pathogens and it is possible that relatively small numbers can cause disease in certain circumstances. For example, the transmissibility of typhoid fever depends upon the ingestion of an effective dose by a new host. Barrier nursing procedures may protect the immediate contacts of an acute case, but the infection is classically transmitted by the inadvertent contamination of a water supply or food with excreted bacilli from a carrier of typhoid. The circumstances usually suggest that a low challenge dose is involved and the sporadic way in which new cases arise, unless a real epidemic gets going, indicates that an extension of the ED_1 concept may be valid. However, it is not fundamentally clear why typhoid differs so markedly in its epidemiology from bacillary dysentery.

Bacillary dysentery is a convincing example of an infection in which a hand-to-mouth transmission appears to operate. Our present evidence suggests that relatively direct spread is involved in this case, perhaps involving 'mediate contact', and that food or drink is not typically involved.

Some forms of infantile gastro-enteritis caused by enteropathogenic strains of *E. coli* share features in common with bacillary dysentery and acute typhoid infections; food and eating utensils and feeding bottles may well be involved here. At the present stage of our ignorance, these diseases can be grouped together on the basis of their hand-to-mouth infectivity or their 'passive transfer' in food or drink, though a clinical bacteriologist, a clinician and an epidemiologist would all argue that these diseases are poles apart. The term 'passive transfer' is coined here to denote transfer without multiplication in the vehicle, but a multiplication stage in food can certainly occur and the challenge could then be even more severe.

Gastro-intestinal infections that can be transmitted by small challenge doses are characteristically difficult to control and are associated with a tendency to spread with the production of secondary cases, despite modern toilet systems (Thomas and Tillett, 1973a, b; Leading Article, 1973). Our lack of care in this context is deplorable, and the design and use of the 'modern' toilet system in general take inadequate note of hygienic principles. This is also true of our catering.

Infections associated with larger challenge doses

Infections that seem to be associated with moderately large challenge doses under certain circumstances include brucellosis, cholera, and *Vibrio parahaemolyticus* food poisoning, with milk, water and fish as the respective vehicles involved. It might be helpful to consider that these diseases, possibly involving quantitatively significant challenges, are 'actively transferred' in their vehicles. The diseases occur when circumstances allow a relatively large challenge to be delivered, but control can be achieved by relatively simple hygienic practices such as pasteurization, sewage engineering, and cold storage.

Infections associated with very large challenge doses

Salmonella food poisoning and *Clostridium welchii* food poisoning operate in entirely different ways. The types of food involved also differ, but in each case a prior booster stage is involved when the infecting organism multiplies in food. Although *Cl. welchii* ultimately presents a toxic challenge *in vivo*, the initial development of the disease depends upon ingestion of large numbers of viable organisms. The mechanism of pathogenicity involved in *Salmonella* food poisoning is not understood, but

again the ingestion of large numbers of viable organisms is characteristically required. In both of these forms of food poisoning, the important point is that a possibly harmless degree of contamination is transformed into an effective challenge at some point in food-handling. The effective dose is generally considered to be some thousands or tens of thousands of organisms of food-poisoning species of *Salmonella* (Taylor and McCoy, 1969), and some millions of *Cl. welchii* (Hobbs, 1969). These conditions illustrate the dangers of the booster effect that occurs when circumstances of time and temperature allow bacterial multiplication in food at some stage in its preparation. It should be borne in mind that some strains of food-poisoning *Salmonella* serotypes have spread among hospital patients in a manner that suggests that low challenge doses of these organisms may sometimes be effective.

Direct toxic challenges

Some bacterial food-poisoning conditions result from ingestion of a toxin that has been preformed in the food. Although the bacteria that produced the toxin are usually ingested along with the toxin, the pathogenesis does not necessarily involve an infective step *in vivo*. The elaboration of an effective dose of toxin depends upon contamination of the food with the toxigenic bacteria; subsequent mishandling of the food allows bacterial multiplication and toxin production.

The classical example is botulism caused by *Cl. botulinum*, especially types A, B and E in the case of man. Some of these organisms can grow and produce toxin at temperatures as low as 1–5°C.

Staphylococcal food poisoning is also a direct intoxication. The staphylococcal enterotoxin (a neurotoxin) is produced when enterotoxigenic strains of *Staphylococcus aureus* grow in certain foods such as salt-cooked meats and dairy products. As the hands are so often involved in contaminating foods with staphylococci and with other potential pathogens, it is perhaps time to discard the term foodhandler as a professional label and to reserve it as a term of abuse in the kitchen when certain foods that should be untouched are handled.

Bacillus cereus, an organism that abounds as an aerobic spore-former in nature, sometimes contaminates foods such as left-over cooked rice and may then grow and produce a toxin. This is associated with a form of Chinese restaurant food poisoning.

Mechanisms of pathogenicity in the intestine

The following patterns of attack have been considered and there is much interest in the mechanisms of pathogenicity that may be involved. Savage (1972) and Craig (1972) have summarized and dis-

cussed some of these (see also Hornick *et al.*, 1970; Formal, Dupont and Hornick, 1973).

(1) Local infection, usually non-invasive, with no single toxin recognized: *Salmonella* food poisoning; *E. coli* gastro-enteritis.

(2) Local infection with local invasion but no recognized toxin: Shigella dysentery (but see van Heyningen, 1971); *E. coli* gastro-enteritis.

(3) Local invasion with generalized invasion; no single toxin incriminated: Typhoid fever and brucellosis.

(4) Local infection with no invasion; enterotoxin produced *in vivo*: *Cl. welchii* food poisoning; cholera; *V. parahaemolyticus* food poisoning; *E. coli* gastro-enteritis.

(5) Direct intoxication with a preformed toxin; infection not primarily involved: Botulism; staphylococcal food poisoning; *B. cereus* food poisoning.

These concepts summarized in Table 1 will require modification as our knowledge advances. Enteropathogenic strains of *E. coli* presently appear to merit classification in various categories and it is possible that the pathogenesis of infantile gastroenteritis differs significantly from that of various forms of *E. coli* diarrhoea that may afflict adults. The potential pathogenicity and transmissibility of some strains of this species, especially among very young children in hospital, are frightening reminders of our lack of understanding of the challenges involved. Parallel studies of diarrhoeal disease in animals (e.g. by Smith and Linggood, 1971) indicate that special antigens may be of importance in allowing a coliform pathogen to colonize and attack a susceptible area of the small gut. The preferential attachment of certain bacterial pathogens to mucosal surfaces has been discussed by Savage (1972). The 'invasiveness' of certain pathogens at the host cell surface may depend upon a phagocytic reaction of the host cell that is triggered by the pathogen.

The population at risk

Although distributors of bulk-produced ingredients and processed foods pay attention to the bacterial content of their products, remarkably little attention has been paid to the bacterial content of foods served at table. As it is presented at table, or in hospital, or in the nursery, our food is regularly contaminated with many different organisms (McKillop, 1959; Riemann, 1969; Anderson and Gatherer, 1970; Ayliffe, Collins and Pettit, 1970; Cooke *et al.*, 1970; Shooter *et al.*, 1970, 1971). Some of these organisms are generally regarded as indices of faecal contamination and the implications are disturbing.

Ideally, hygienic precautions should be taken to minimize the degree of initial contamination, and a subsequent bactericidal heat-treatment should re-

TABLE 1. A provisional guide to some features of the causative organisms of various food-borne diseases

Disease	Transmission	Infective challenge dose involved	Invasiveness	Known toxic challenge*
Bacillary dysentery	Hand-to-mouth	+	Local	—
Typhoid fever	'Passive' in water, milk or food	+	General	—†
<i>Escherichia coli</i> gastro-enteritis	? Passive in water, milk or food	? +, ++ or +++	Local or nil‡	— or + (<i>in vivo</i>)
Brucellosis		++	General	—
Cholera		++	—	+ (<i>in vivo</i>)
<i>Vibrio parahaemolyticus</i> food poisoning	'Active' in food	++	—	+ (<i>in vivo</i>)
<i>Salmonella</i> food poisoning	Booster stage in food or milk	+++	Local‡	—†
<i>Clostridium welchii</i> food poisoning	Booster stage in food	+++	—	+ (<i>in vivo</i>)
Staphylococcal food poisoning	Booster stage in food or milk	—	—	++ (EXO) (N)
<i>Bacillus cereus</i> food poisoning	Booster stage in food	—	—	++ (EXO)
Botulism	Booster stage in food	—	—	+++ (EXO) (N)

* '*In vivo*' here indicates that toxin is elaborated within the gut; 'EXO' indicates that a known exotoxin is recognized; 'N' indicates neurotoxic activity.

† The endotoxins of various pathogenic Gram-negative bacteria are toxic, but the pathogenicity of these organisms is not solely attributable to their production of endotoxin.

‡ Some of the food-poisoning salmonellae, notably *S. typhimurium*, are occasionally invasive.

§ *E. coli* may be fiercely invasive in the neonate or young child.

— = nil or not recognized;

+, ++, +++ = increasing numbers of viable organisms (challenge dose) or increasing severity of toxic challenge.

duce any challenge still further. The pasteurization of milk is a good example, but our record with cream is not good (Leading Article, 1970a). Circumstances that lead to certain food-poisoning hazards are now clearly defined and we should at least be able to exclude gross bacterial contamination of our food during its preparation. That this is not achieved is clearly shown by the statistics for *Cl. welchii* food poisoning, for example. The occurrence of this form of food poisoning is a direct indictment of the catering practices involved, yet we continue to have many outbreaks.

Table 2 summarizes results of studies on carriage rates for so-called typical food-poisoning strains of *Cl. welchii*. Although it is now known that other strains of *Cl. welchii* can cause food poisoning, these data are still of interest. Sutton (1966a, b) was able to correlate high carrier rates of typical food-poisoning strains with communal feeding and with poor hygiene. It is disturbing that relatively high carriage rates were generally reported among hospital patients and personnel by various workers. This probably unfairly singles out hospitals for criticism because medical research workers tend to turn their attention to hospitals for their material. It is quite likely that institutional meals in general, and possibly

many bulk-cooked meals, fall short of acceptable bacteriological standards. A recent leading article (*British Medical Journal*, 1972b) entitled 'Bad Food Guide' draws attention to some current trends in catering that give cause for concern, and another leading article (*British Medical Journal*, 1970b) indicates hazards to man that may result when animals are fed with infected feeding-stuffs. It is also clear that standards of care in the home are not good enough. For example, the survey of the hygiene of infant-feeding utensils by Anderson and Gatherer (1970) demonstrated that there is much room for improvement and indicates why *E. coli* gastro-enteritis still has many opportunities to demonstrate its lethal potential in infants.

It appears that different age-groups and different sections of the community are particularly likely to encounter or to be affected by certain challenges. The recognized hazards include infantile gastro-enteritis in the first 2 years, and bacillary dysentery at nursery school and primary day school. At all ages, a variety of challenges ranges from *Salmonella* infections, which are widespread, to *Cl. welchii* food poisoning particularly associated with bulk-cooked meat foods at school, hospital or canteen. Other forms of food poisoning or food-borne infection may

TABLE 2. Reported faecal carrier rates for heat-resistant strains of *Clostridium welchii*

Year	Authors	Population	Country	Carrier rate (%)
1953	Hobbs <i>et al.</i>	General	England	2.2
1957	Dische and Elek	Hospital and hospital-associated	England	20
1961	Leeming, Price and Meynell	Hospital (recently admitted patients)	England	14.5-22
		Hospital (established inpatients)		30-32.5
1961	Turner and Wong	Hospital and hospital-associated	Hong Kong	63
		General	England	9
1961	Collee <i>et al.</i>	Students	Scotland	6-8
1966b	Sutton	General	Australia	1.5-6.0
		Subjects associated with communal feeding and/or poor hygiene		15.1-25

be respectively associated with such special hazards as meat sandwiches bulk-produced at home, or a Chinese restaurant meal prepared under unhygienic circumstances, or contaminated sea-food eaten raw.

Prevention by education

Some of our raw food is quite seriously contaminated at source; for example *Cl. welchii* is ubiquitous, and salmonellae are often associated with intensively reared chickens, calves and pigs. The handling of raw foods and ready-cooked processed foods in the same kitchen, on the same work surfaces and sometimes with the same utensils, therefore merits special consideration in relation to the hazard of cross-contamination. However, conditions such as salmonella food poisoning and *Cl. welchii* food poisoning are not likely to be produced unless the primary contamination is gross or the challenge dose is boosted in a suitable food that allows growth of the causative organism. With much of our processed food nowadays, particularly in restaurants, canteens and institutions, the importance of time and temperature in relation to bacterial growth and toxigenesis is not adequately stressed.

The significance of the thermometer scale illustrated in Fig. 2 should be clear to every caterer. The booster effect normally illustrated as a logarithmic plot (the bacterial growth curve) is not readily comprehensible in arithmetical terms to catering staff of limited academic background. Perhaps the 'biological clock' shown in Fig. 3 has a greater impact. The counts given in the clock diagram are based on a mean generation time of 20 min, a generally accepted value for mesophilic bacteria multiplying in the exponential phase under good conditions. Actual data obtained with *Cl. welchii* (Collee, Knowlden and Hobbs, 1961) show that even greater rates of division

can be achieved at temperatures up to 45°C with this organism growing in a medium resembling a cooked meat food.

Processed meats and meat foods are frequently incriminated in food-poisoning outbreaks. Our society is now geared to the large-scale consumption of processed meats and to bulk catering, and our catering areas and domestic kitchens are usually centrally heated. We have been slow to install adequate chilling plant and refrigeration facilities to protect our foods during preparation or holding periods under these circumstances. The message of Fig. 4 might literally bring the point home, but it must also be conveyed to firms and boards of management that modern catering demands modern equipment.

Indirect challenges

This is an intriguing area for discussion. Our consumption of sugar and sweets encourages bacterial production of dextrans in the mouth and this is related to dental plaque formation and to dental caries. It can therefore be argued that some of our modern foods have unsafe effects on our commensal flora and this thesis can be extended.

The ability of commensal *Cl. welchii* and *Bacteroides* species in the gut to alter steroid-like molecules and to transform them into potentially carcinogenic agents (Hill *et al.*, 1971) is of interest to the clinician concerned with diet in relation to bowel stasis and slow transit times.

Coliform organisms ingested in food may carry resistance transfer factors (RTF). If a patient harbouring such organisms is given an oral broad-spectrum antibiotic (A), there is a possibility that resistant organisms, including those with the RTF, will be selectively favoured and will become much more

FIG. 2. Holding temperatures in relation to the hazard of growth of mesophilic bacteria in food.

numerous (Anderson, Gillespie and Richmond, 1973). When the RTF-bearing organisms are relatively numerous, the chances of spread of the RTF to other organisms in the gut are increased and this may involve a pathogen. Under these circumstances, for example, an antibiotic-sensitive strain of a dysentery bacillus would promptly become resistant to antibiotic (A) and to several other antimicrobial substances for which the RTF carried the necessary genetic information. Antibiotic therapy is not recommended in most cases of dysentery, but, for example, the principle has worrying parallels in relation to typhoid fever.

The challenge of diagnosis

It has been necessary to limit this discussion to certain bacterial diseases, and to exclude other conditions such as abdominal tuberculosis, streptococcal

FIG. 4. A suggested statement of priorities for a society that consumes many processed foods.

our technology to make food safely and to keep it safe have been developed and are observed by the large commercial undertakings who recognize the health risks and the financial risks involved. This requires control of the standard of ingredients and raw materials and subsequent control at all stages of processing, holding and distribution. Then the baton of responsibility for care is often passed to the retailer, the caterer or the householder. Present evidence suggests that it is not infrequently dropped at that stage and that we may unwisely challenge our babies, our patients and the general public. These are not 'natural' challenges, any more than feeding bottles or processed foods are 'natural'. The risks involved have been contrived by man whose changing practices and procedures allow special bacterial challenges to evolve and to be delivered. The present symposium is therefore timely.

It is not possible to give an unqualified assurance regarding the safety of our food. Although it must be conceded that less harm seems to arise than an alarmed bacteriologist might predict, very disturbing

examples of carelessness are frequently reported and many people are annually affected with food-borne disease. It seems clear that more care is needed.

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