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New directions in foodborne disease prevention

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Abstract

Food safety is an important part of public health linking health to agriculture and other food production sectors. For over a century, developments in food production and new control philosophies have contributed to food safety systems in most developed countries perceived by many to be efficient in the prevention of foodborne disease. Nevertheless, a number of problems still remain dominant, one of these being the high level of foodborne microbiological diseases which seem, for some pathogens, to have increased over the last decades. Although there is an urgent need for better foodborne disease data in most countries, the paper attempts an analysis of the background to these problems using available data to illustrate the developments for some of the major foodborne pathogens. Some of the shortcomings of present food safety systems are discussed, as are new principles to improve food safety strategies. A new paradigm for the integration of research data, food-control monitoring, epidemiological investigations and disease surveillance in a renewed effort to manage and lower foodborne risk is presented. Within this paradigm, the development of an interdisciplinary approach with direct interaction between surveillance and risk analysis systems is described as a potential basis for improved foodborne disease prevention. Specific consideration is given to the situation in developing countries, suggesting a leap forward past the experience of noncollaboration between the disciplines in many developed countries. Today, food safety is one of WHO's top 11 priorities and the Organisation calls for more systematic and aggressive steps to be taken to significantly reduce the risk of microbiological foodborne diseases. Dealing with this challenge is one of the major challenges for the 21st century in regard to food safety, implying a significant redirection of food microbiology efforts in many parts of the world.

Keywords: WHO; Food; Safety

1. Introduction

Food safety and food control have been recognised as important issues in many countries for decades. Many major initiatives both in safe food production and in control philosophy have contributed to systems in most developed countries perceived by many to be efficient in the prevention of foodborne disease. The recent outbreaks of foodborne disease have, however, shaken the consumers' trust in these food safety systems. BSE, dioxin, *Escherichia coli* O157, *Salmonella*—all foodborne hazards that were virtually unknown 10 years ago—are now household names in most families. In almost all cases, major outbreaks of disease or contamination have been the reasons behind this rise to fame.

Many countries now realize that foodborne disease continues to be a major public health issue. Food-

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borne diseases are some of the most widespread health problems in the world and they have implications both on the health of individuals and the development of societies. Deeply concerned by this, the Fifty-third World Health Assembly, the governing body of the World Health Organization (WHO), in May 2000, adopted a resolution calling upon WHO and its member states to recognize food safety as an essential public health function (WHO, 2000a). The resolution also called for the development of systems to enable a reduction of the burden of food borne disease.

This paper will focus on the developments in food safety and especially foodborne microbiological disease over the last decades. It will attempt to analyse the background for the seemingly emerging and increasing problems. New principles to improve food safety strategies and systems are discussed, as is the need for a new paradigm for integration of research data, food-control monitoring, epidemiological investigations and disease surveillance in a renewed effort to manage and lower foodborne risk.

2. Chemical and microbiological hazards and risks from food

A food hazard is defined as "a biological, chemical, or physical agent in or property of food that may have an adverse health effect," and a food related risk is traditionally defined as "a function of the probability of an adverse effect and the magnitude of that effect, consequential to a hazard in food" (WHO, 1995).

Chemical additives or microbiological starter cultures are examples of potential hazards usually controlled before addition to our food. The presence of chemical or microbiological hazards entering the food as contaminants can be followed through monitoring programs. Differences in chemical and microbiological detection methodology result in different availability of monitoring data of these groups of contaminants. However, more importantly, the difference in the nature of the hazards results in an even more significant difference in disease link potential. While microbiological foodborne disease can often be related directly to a pathogen with potential presence in food, this is not the case for disease related to chemical hazards in food. Therefore, comparing microbiological and chemical foodborne risk is difficult.

The focus of this paper on microbiological risk relates to the topic at hand and should not be taken as a reflection of relative importance of such risk compared to chemical risk.

3. Impact of microbiological foodborne disease

It is difficult to obtain accurate estimates of the incidence of microbiological foodborne disease. A population-based study conducted in the Netherlands estimated the total annual incidence of gastroenteritis to be 28%, without attributing the degree of foodborne or microbiological aetiology (Wit et al., 2001). In the United States of America (USA), it has been estimated that 76 million cases of foodborne diseases may occur each year, resulting in 325,000 hospitalisations and 5000 deaths (Mead et al., 1999). Extrapolating the US data to the rest of the world would mean that up to one third of the population in developed countries are affected by microbiological foodborne disease each year, while the problem is likely to be even more widespread in developing countries (Käferstein and Abdussalam, 1999). The poor are the most susceptible to ill health. Food and waterborne diarrhoeal diseases, for example, are leading causes of illness and death in less developed countries, killing an estimated 2.1 million people annually, most of whom are children (WHO, 2001). Diarrhoea is the commonest symptom of foodborne illness, but other serious consequences include kidney and liver failure, brain and neural disorders and death. The debilitating long-term complications of foodborne disease include reactive arthritis and paralysis.

Foodborne diarrhoea provides one of the strongest direct links between food safety and food security, since the most important cause of increased host susceptibility to foodborne infections is malnutrition. UN's Food and Agricultural Organization (FAO) estimates that malnutrition affects about 800 million people. Malnutrition increases host susceptibility to foodborne infections through a number of mechanisms. Diarrhoea caused by *E. coli*, which is probably the most important cause of children's diarrhoea in developing countries, have a longer duration and a greater potential for long-term nutritional consequences in malnourished children. In general, malnutrition can result in a 30-fold increase in the risk for diarrhoea associated death (Morris and Potter, 1997).

Serious outbreaks of foodborne disease have been documented on every continent in the past decade, illustrating both the public health and social significance of these diseases. Consumers everywhere view foodborne disease outbreaks with ever-increasing concern. As described in Section 5, outbreaks are likely, however, to be only the most visible aspect of a much broader, more persistent problem.

The availability of safe food improves the health of people and is a basic human right. Safe food contributes to health and productivity and provides an effective platform for development and poverty alleviation. Foodborne diseases not only significantly affect people's health and well-being, but they also have economic consequences for individuals, families, communities, businesses and countries. These diseases impose a substantial burden on health-care systems and markedly reduce economic productivity. The loss of income due to foodborne disease perpetuates the cycle of poverty. Estimating direct as well as indirect cost of foodborne disease is difficult. An estimate in the USA places the medical costs and productivity losses in a population of approximately 250 millions in the range of US$6.6–37.1 billion (Butzby and Roberts, 1997).

4. Foodborne disease data

4.1. Data collection

Foodborne disease data can be collected through surveillance activities, outbreak investigations and conducting special studies.

Routine surveillance of human illness provides information about illnesses possibly due to food and is conducted only on persons who become ill. Routine surveillance provides information on trends in illness and, therefore, facilitates detection of outbreaks and the estimation of the burden of disease. Enhanced surveillance, e.g. routine follow-up of people who are infected to determine rates of exposure and illness outcomes, can provide more complete information such as burden of disease with regard to hospitalization, sequelae and deaths, etc. Integrated surveillance represents the ideal situation with an integration of human, animal and food surveillance activities. This involves collecting consistent and validated information from processes throughout the food continuum from farm to patient.

Outbreak investigations represent a natural source of useful data even though in the majority of foodborne disease outbreaks, the contaminated food is no longer available for testing. However, certain outbreaks provide very valuable information for characterization of the hazard as well as future prevention. Some countries have been able to increase the frequency of useful information from outbreak investigations through food saving systems aimed at the retention of food from large-scale catering facilities.

Special epidemiological studies are often costly and require intense planning. These studies generally focus on sporadic illness and include cross-sectional, case control, cohort or other experimental designs.

In general terms, food borne disease surveillance is essential for:

- estimating the burden of food borne diseases, and monitor trends;
- identifying priorities and setting policy in the control and prevention of food borne diseases;
- detecting, controlling and preventing food borne disease outbreaks;
- identifying emerging food safety issues; and
- evaluating food borne disease prevention and control strategies.

4.2. The lack of data

As most cases of foodborne disease are not reported, the true dimension of the problem is unknown. The absence of reliable data on the burden of food borne disease impedes understanding about its public health importance and prevents the development of risk-based solutions to its management. The World Health Assembly Resolution on Food safety from May 2000 encourages WHO member states "to implement and keep national and, when appropriate, regional mechanisms for foodborne disease surveillance" (WHO, 2000a).

With the exception of cholera, which, together with yellow fewer and plague, is subject to the WHO

International Health Regulations, there is no obligation to report foodborne disease internationally. In most countries, only a few diseases which are or may be of foodborne origin appear on the list of notifiable diseases. In addition, the reported diseases are not presented in a uniform manner. While one country may report the incidence of shigellosis and amoebiasis separately, another may report them jointly under the term dysentery. Likewise, the meaning of the term food poisoning varies from country to country and, not infrequently, it is used to represent different groups of diseases.

A major source of international variability in reporting relates to the number of sporadic cases. Some countries report the total number of cases of a foodborne disease, including sporadic cases, while others mainly collect information on the number of outbreaks and the number of cases involved in the outbreaks. For most foodborne diseases, the major part of cases are sporadic; for some diseases (e.g. campylobacteriosis), the disease incidence relates almost exclusively to sporadic cases (WHO, 2000b).

In most countries, the surveillance infrastructure is weak or nonexistent. Furthermore, in many countries, particularly in the developing world, laboratory resources and skills to identify pathogens are scarce, and etiology-specific surveillance is often not possible. Even in the developed countries, laboratory-based surveillance is not well developed. In addition, for some agents, e.g. enteric viruses, the absence of a simple and reliable diagnostic test makes surveillance difficult.

Traditionally, the reporting of foodborne disease at the national level is based in some way in the number of laboratory confirmed cases, either related to a certain subset of the population or on a national basis. Since many cases of foodborne disease will never reach the health system, and since only a fraction of the cases reaching the health system, will actually go through laboratory confirmation, the number of laboratory confirmed cases only represents a fraction of the real cases. The factor between reported and real cases is called the underreporting factor. Few thorough epidemiological estimations of the national underreporting factor have been made, but there are significant variations in the factor used. One example of such variation is that for salmonellosis the factors can vary from 3.2 from a study in the UK (Wheeler et al., 1999) to 38 from a study in USA (Mead et al., 1999). It is not easily evaluated whether differences in the underreporting factor between countries is a reflection of real differences in the performance of health systems or a reflection of differences in methodology used to estimate the factor.

In addition to systemic difference, also the variation between countries in the perceived importance of diarrhoea as a disease for which one would seek medical attention will influence surveillance data. Differences in population characteristics have to be included in the considerations when comparing reported foodborne disease data.

One important area of data need is the need for data on food contamination throughout the foodchain. This paper will primarily deal with disease data but it is important to emphasize that the linkage between bacterial contamination of food and foodborne disease should be considered one of the most important areas of need for additional data. For preventative purposes, the analyses and interpretation of foodborne disease surveillance data requires an associated and similar approach for data from food monitoring. The most modern and scientific way to perform that is to use the risk assessment process (see Section 7). Previous FAO/WHO consultations have stressed the need for collecting additional data, especially in developing countries, for microbiological risk assessment. The integration in a single approach of both foodborne disease surveillance and food monitoring could provide the data which are crucial for risk assessment. This would be useful not only for the country under study but also for neigbouring countries sharing high similarities in terms of food safety characteristics (FAO, 2001). Investigating the full linkage from farm to table, continuing in some cases all the way to the hospital bed is likely to be a necessary prerequisite for improved preventative efforts.

Finally, one important constraint in presenting information at the international level should not be underestimated. This relates to the repercussions that information on foodborne disease epidemics, foodborne disease incidence or food contamination may have on food trade and tourism. Concern about the possibility of food export being rejected and/or loss of tourism have been a disincentive for many governments to release information on foodborne disease and foodborne contamination.

5. Trends in microbiological foodborne disease

5.1. Enterohaemorrhagic *E. coli*

Enterohaemorrhagic *E. coli* (EHEC), of which *E. coli* O157:H7 is the most well-known, is a group of enteric pathogens which only since 1982 have been recognised as foodborne human pathogens. Although the overall incidence of disease caused by EHEC is low, the life-threatening complications of infection in young children and the elderly is cause for serious concern. New research in this area seem to indicate that EHEC is fairly prevalent in the bovine intestine, but uncertainties related to isolation, typing and virulence characterisation of this subgroup of the intestinally ubiquitous *E. coli* is complicating the picture (WHO, 1997).

5.2. *Listeria monocytogenes*

Some previously well-known pathogens have only recently been shown to be predominantly foodborne. For example, *L. monocytogenes* was long recognised as a cause of meningitis and other invasive infections in immunocompromised hosts. How these patients became infected remained unknown until a series of investigations in the 1980s identified food as the most common source (Jackson and Wenger, 1993).

5.3. BSE

Bovine spongiform encephalopathy (BSE) was first discovered in the UK in 1985. A series of measures were introduced as from 1987 in the UK and 1991 in the countries of continental Europe where BSE cases were first identified. Because of the long incubation period (mean 60 months), it is not possible to determine promptly the effect of new measures introduced to reduce risks. This creates uncertainty in their effectiveness of some year's duration. However, there is evidence from the UK that an epidemic of BSE can be contained, reduced and probably eliminated. In human populations, exposure to the BSE agent has been strongly linked to the appearance in 1996 of a new transmissible spongiform encephalopathy of humans called variant Creutzfeldt-Jakob Disease (vCJD), with a presumed fatality rate of 100%. As of January 2002, 119 people have developed vCJD, most are from the UK but five cases have been reported from France. (WHO, 2002). The development in human disease is difficult to predict, primarily because of the lack of knowledge of the mean incubation period.

5.4. *Salmonella*

Salmonellosis is one of the most frequently reported foodborne diseases worldwide. According to the WHO Surveillance Programme for Control of Foodborne Diseases in Europe (currently 50 countries participating), incidences of salmonellosis in the region have shown some temporal trends (Anonymous, 2000b). Since 1985, there has been a tremendous increase in the incidence of salmonellosis in many countries, with a peak being reached in 1992, or even earlier in some countries (Fig. 1). Retrospectively, it can be stated that there was an epidemic caused by *S. enteritidis*, but since then the incidence of salmonellosis has decreased, due to the control measures implemented and to a greater awareness of the risk among the public. In other countries of the region, the greatest incidence of salmonellosis appears after a timelag, between 1995 and 1997, and in few others, the incidence of salmonellosis is still increasing. In some of the new Central Asiatic Republics, the reported cases of salmonellosis have been relatively low or even decreasing from 1993 to 1998. This may not necessarily reflect a real decrease of the incidence of salmonellosis but rather that the surveillance systems in these new countries are not yet fully developed.

For *Salmonella* spp., in some cases, a rapid spread through the animal production systems seems to have occurred at a global level in recent decades. *S. enteritidis* appeared simultaneously around the world in the 1980s (Rodrigue and Tauxe, 1990), most likely also spreading into the poultry production systems of developing countries in the 1990s (Matope et al., 1998).

Data collected by WHO of *Salmonella* serotype distribution from human cases shows a dramatic relative increase in *S. enteritidis* within the last decades (Fig. 2).

Another case of spread in the animal population, followed by a corresponding occurrence of human cases is the multiresistant *S. typhimurium* Definitive Type (DT) 104 which has spread rapidly in many European countries, North America and perhaps else-

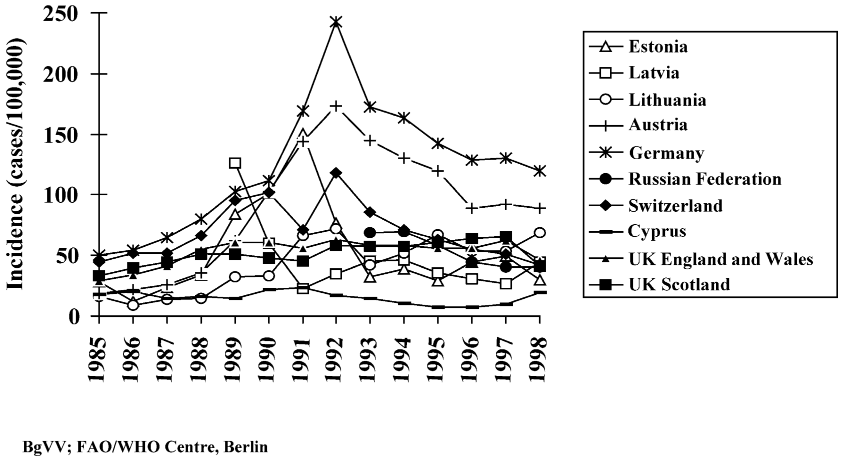

Fig. 1. The reported incidence of salmonellosis in some European countries (1985–1998).

where from the beginning of the 1990s (Anonymous, 1997). An interesting comparison of the relative increase in DT104 isolates from the bovine and human population in the northwestern part of USA is presented in Fig. 3 (Davis et al., 1999).

5.5. *Campylobacter*

Reports of campylobacteriosis cases have been continuously increasing in many parts of the world since 1985. Currently, *Campylobacter* is the most common gastrointestinal pathogen in many countries, including many European countries (see Fig. 4) (Anonymous, 2000b). In several countries, it is still unclear whether the increase observed can be attributed to a real increase in incidence, or to an improvement in diagnosis, or to both. Most reported cases of campylobacteriosis occur sporadically, as single cases, or small family outbreaks, and are generally caused by *C. jejuni*.

Globally, *Campylobacter* diagnostical capacity is still under development, and it is likely that the true burden of disease caused by this pathogen is seriously underestimated in many countries (WHO, 2000b).

5.6. Antimicrobial resistance

The emergence of bacteria resistant to antimicrobial substances has added to the problems of foodborne disease. The major reason for increasing antimicrobial

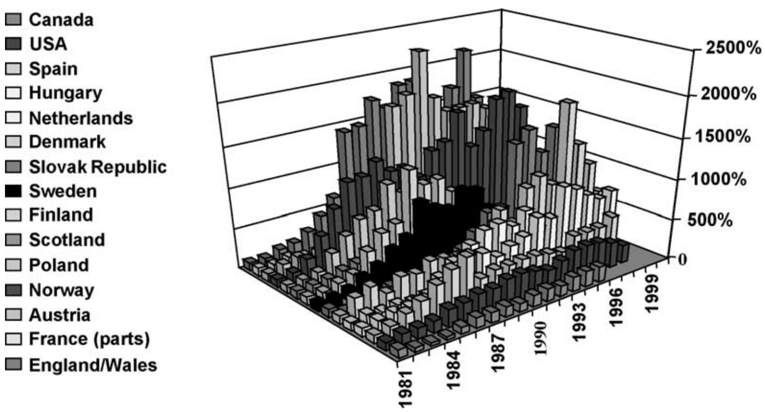

Fig. 2. *Salmonella enteritidis*, percent increase in human infections, Europe and North America (1981–2000, 1981: 100%).

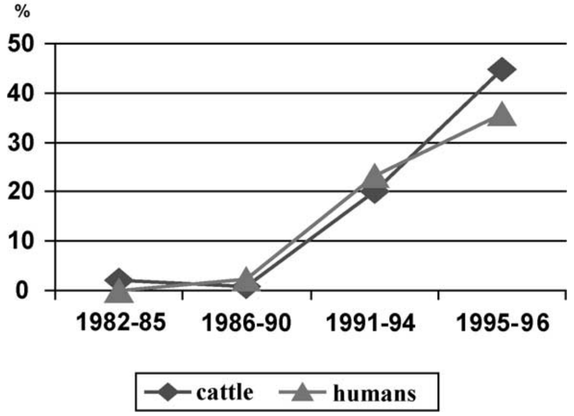

Fig. 3. Percentage multidrug resistant *Salmonella typhimurium*, type (DT) 104: cattle and humans, Northwestern USA (1982–1996).

resistance in important pathogens in general is the widespread use of antimicrobials in hospitals and the community. However, large amounts (about 50% of the overall production) from almost all classes of antimicrobials are used in animal production, including aquaculture, for disease control and growth promotion. Thus, also foodborne pathogens have become increasingly resistant to antimicrobials, resulting in human infections which are more difficult to treat as well as increased mortality. The problem is not yet fully described, but there seems to be agreement that treatment of important human infections should not be compromised by unnecessary nonhuman use of antimicrobials (WHO, 2000c).

5.7. Active disease surveillance

The introduction of active surveillance through sentinel systems is likely to result in better and more reliable disease incidence estimates in the future. New initiatives to this end have been taken in different parts of the world. In USA, a system has been developed to include active surveillance for culture-confirmed cases of *Campylobacter*, *E. coli* O157, *Listeria*, *Salmonella*, *Shigella*, *Vibrio*, *Yersinia*, *Cyclospora* and *Cryptosporidium* in five surveillance sites covering 16.1 million persons or roughly 6% of the US population. Results from 1997 demonstrate that while there are regional and seasonal differences in reported incidence rates of certain bacterial and parasitic diseases, and that some pathogens showed a change in incidence from 1996, the overall incidence of illness caused by pathogens under surveillance in USA was stable (Wallace et al., 1997). The authors caution that more data over more years are needed to assess if observed variations in incidence reflect yearly fluctuations or true changes in the burden of foodborne illness. In a later report, the sentinel site surveillance data for 1999 is compared with data from

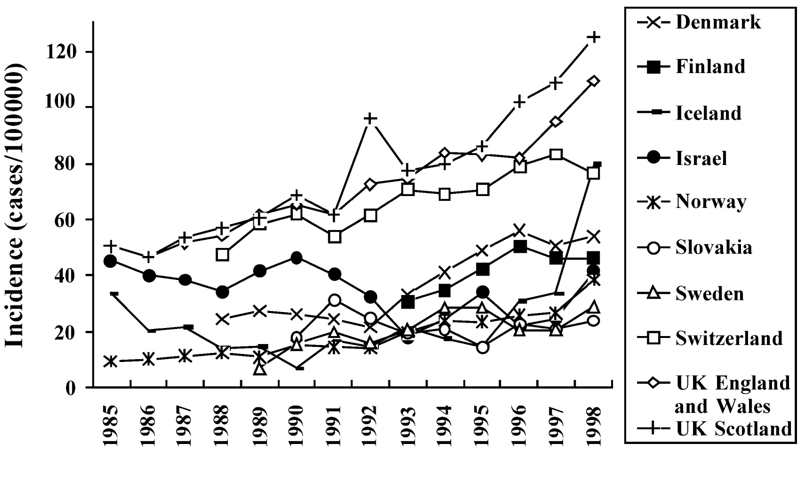

Fig. 4. The reported incidence of campylobacteriosis in some European countries (1985–1998).

1996 to 1998, suggesting that the incidence of the foodborne diseases under surveillance declined during 1999 compared with 1996 primarily as a result of decreases in campylobacteriosis and shigellosis but at the same time indicated substantial regional variation in the incidence of foodborne diseases (Anonymous, 2000a).

5.8. General aspects

In general, there seems to have been significant changes related to foodborne microbiological diseases, some of which seem to have been on the increase in many countries. Any statement on an increase in disease incidence needs to be considered in the light of the efficiency of disease surveillance systems discussed above and the impact of potentially better reporting. However, it is interesting to note that for both *Salmonella* and *Campylobacter*, the situation seems to have changed over time in a similar manner in many different countries over the last two decades. These changes seem to have been different from developments in other, similar intestinal zoonotic pathogens, such as *Yersinia*, suggesting that improved reporting for foodborne diarrhoea in general would not seem to be the major cause for the observed changes.

More importantly, the mere magnitude of the problems as realized at present is certainly enough to merit consideration of the efficiency of our present preventative systems, irrespective of the past. In doing so, the temptation of defining the real problem as one of loss of consumer confidence should be avoided. Loss of consumer confidence is only a symptom of deeper problems. The only way to regain consumer confidence is through efficient dealings with the real problems.

6. What went wrong?

There are several major issues at the core of the food safety problems experienced in most parts of the world. The most important are the following.

(1) The prevention of problems have to integrate the full food production chain: From Farm to Fork, or from Boat to Throat, recognizing that the critical point for efficient prevention might be at the farm for some problems or at the retail level for others. Most present food safety systems are not build according to this important principle. Such incoherence of the systems have led to inconsistency and in some cases inefficiency of food safety systems.

(2) The preventative work at the farm, at the production sites, at retail, with the consumer, even the link to the patient suffering from foodborne disease—all these links call for interdisciplinary collaboration. Such collaboration is lacking in most present systems. The lack of collaboration again leads to heterogeneity and inefficiency of the preventative food safety efforts.

(3) While prevention of foodborne disease of course has to be based on good general hygienic practices, it is important to focus our efforts towards the real risks in the population. This should be done through the use of new risk-based approaches, including the use of Risk analysis as an important cornerstone in our regulatory framework. This has generally not been done in the past, leading to the waste of precious funding in areas, that do not target foodborne disease, while activities focusing on disease characterization and prevention have in many cases lacked appropriate funding.

(4) Any system to prevent efficiently foodborne disease problems should be based upon a solid evidence base. Therefore, the data-gathering efforts related to food contamination and foodborne disease need to be coordinated. Likewise, monitoring, surveillance and control efforts should be geared towards common goals, and research efforts in food and clinical microbiology should support such goals. This coordination is missing in many food safety systems presently, leading to a very weak evidence base, potentially leading to uninformed decisions and poor political support.

(5) An important prerequisite for efficiency in most areas of work is the setting of realistic targets and the monitoring of success/failure. Following from a number of the issues mentioned above, it has not been possible in the past to link food safety efforts directly to foodborne disease risk. Compliance with existing regulation has often been the only measure of success. The lack of clearly communicated targets for disease reduction is still a major drawback of existing food safety systems, although some countries are now initiating major risk-based, target-driven efforts to improve food safety.

7. The risk-based approach

7.1. The risk analysis framework

Risk analysis is a process consisting of three components: risk assessment, risk management and risk communication. Risk assessment is a scientifically based process estimating risk using quantitative or qualitative expressions and including indications of the attendant uncertainties. Risk management is the process of weighing policy alternatives and selecting appropriate prevention and control options, based on risk assessment and other relevant factors. Risk communication is the interactive exchange of information and opinions throughout the risk analysis process.

The risk analysis framework, as it is being developed—among others by WHO and FAO—is based on a participatory approach. All interested parties or stakeholders in food safety, including producers and consumers, should be involved in the management process. While the regulators necessarily are given the overall responsibility, we all need to be involved in the analysis of problems and development of potential solutions. Therefore, the assessment and management parts of risk analysis are sometimes presented as floating in a sea of risk communication, which thus provides the basis for interaction between all the players, including consumers, producers and other stakeholders (Fig. 5).

The new line of risk-based approaches will enable the setting of national and international targets for disease reduction, as well as provide the evidence—basis for such reduction efforts. These approaches will make their way into all parts of the global market, including the developing countries, which are likely to become more and more important agricultural producers. WHO believes that the introduction of a risk-based framework will enable developing countries to learn from mistakes (and successes) elsewhere. These countries have the potential to "leap forward" into preventative systems focusing on risks. Hopefully this will enable the introduction of cost-effective risk mitigation strategies, tailored to national needs. In addition, at a time where trade restrictions and national/regional protection of the agricultural production through heavy subsidies is likely to come to an end, it will be of paramount importance for the production sector also in developing countries to adapt to the new times. The benefits of improving food safety amount to a win–win situation with im-

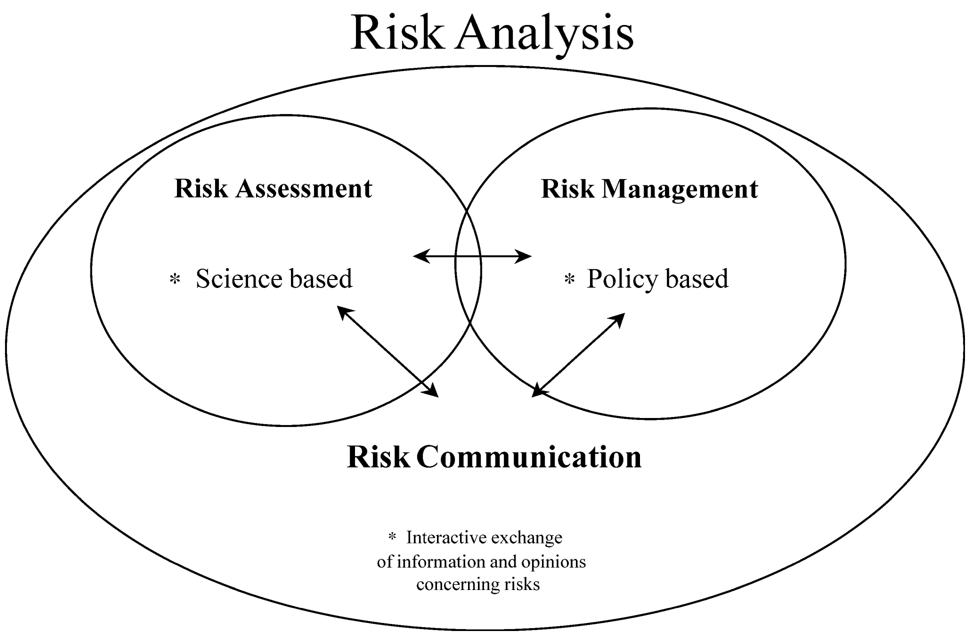

Fig. 5. The risk analysis framework.

proved national health as well as improved export potential.

7.2. Focus for change

At present, many important foodborne pathogens have an animal reservoir from which they spread to humans, i.e. they are zoonotic pathogens. A number of these zoonotic pathogens do not generally cause illness in the animal infected, and traditional food control regimes aimed at detecting animals with signs of disease, such as traditional slaughterhouse meat control, therefore, do not cater for public health concerns in this area.

Very often, the public health problems related to zoonotic pathogens relate to faecal contamination of the slaughtered animal or animal product. Experience from some countries indicates that while the risk of faecal contamination of the meat cannot be fully eliminated, new procedures at the slaughterhouse can lower the prevalence, especially through modification of the cross-contamination potential (Mousing et al., 1997).

The Hazard Analysis Critical Control Points (HACCP) approach, which has already been introduced in many food-producing companies, has also resulted in greater producer responsibility for the safety of food. However, the farm-to-table risk analysis process will take this further, and the producers could play an increasingly important role in this process.

Some of the present food safety problems relate to poverty and development. However, the magnitude of food safety problems in the developed world shows us that development alone is not the answer. In fact, industrialised farming could in some cases be part of the problem. Therefore, the goal should be to describe the contamination and disease problems scientifically at a national or regional level, and use this description to define national, regional or international management options to lower the disease burden. The potential for an international exchange of experience and scientific information in this area is evident, and the spread of risk assessment data and methodology is an important international task for the future.

Investigation of foodborne outbreaks as well as sporadic cases often requires a careful evaluation of the chain of production, i.e. a traceback. In the future, new typing methodology is likely to improve the linking of cases in widely disseminated outbreaks which would previously be considered isolated sporadic cases only. In general, addressing emerging foodborne disease will require more sensitive and timely surveillance, enhanced methods of laboratory identification and subtyping and identification of effective prevention and control strategies.

Sustainable development of agriculture at the global level will be in the interest of everybody. In the long term, it is not sustainable to have very concentrated agricultural production systems in restricted geographical areas, leading to environmental and human health problems. The spread of new food production and food safety ideas to the global arena will prepare the way for sensible, sustainable development in developing countries, and support improvements in health and development of these countries.

Unfortunately, the recent and tragic events in USA on 11 September 2001 have focused a new angle to the debate of food safety: the issue of bioterrorism. Intentional chemical and microbiological contamination of our food chain is a realistic possibility. This realization is not new and activities have been ongoing in this area. However, the September events have refocused the efforts. Agricultural production systems and food processing facilities are potentially at risk. Our efforts towards prevention should be integrated in existing systems. Critical points for control should be defined within for example existing Hazard Analysis Critical Control Points (HACCP) systems. Likewise, existing surveillance and monitoring systems for foodborne disease and food contamination should be expanded to include the bioterrorism threats. This way, hopefully, these new activities will support our general food safety efforts in stead of detracting from it.

7.3. The new methodology—microbiological risk assessment

The overall goal of strengthening foodborne disease surveillance is to provide countries with the necessary data to reduce the foodborne disease burden by providing information, which allows the food safety system to be improved. To design public health policies and identify appropriate food safety measures, data from foodborne disease surveillance need to be analysed together with data from food monitoring systems.

In many cases, data already exist on diarrhoeal disease, although these data may be of poor quality, use nonspecific case definitions and come from poorly defined populations. Even in the absence of laboratory services, these kinds of data can be developed more systematically in selected areas and can be expanded to include information about the severity and impact of disease: work loss, medical visits, costs of treatment, hospital admission, death, etc.

In the absence of local information, data from neighbouring countries or surveys that may have already been done, including published studies, may provide an adequate estimate. Basic laboratory services are required to develop a more sophisticated profile. These resources should be focused in selected sentinel sites, using appropriate sampling strategies to assess the prevalence of various pathogens in patients with diarrhoeal disease. Ideally, such surveys would include methods to identify common bacterial, parasitic and viral enteric pathogens. Data about the relative prevalence of specific pathogens may provide some clues to dominant modes of transmission.

The microbiological risk assessment framework, currently under development by WHO and FAO provides a structured and scientific approach to evaluate the complex issues associated with food hygiene and foodborne diseases. The overall objective of risk assessment is to provide estimates on the probability of disease occurrence using a well structured approach based on four steps: hazard identification, hazard characterization (dose–response), exposure assessment and risk characterization. The Joint Expert Meeting on Microbiological Risk Assessment (JEMRA) is the vehicle established by FAO and WHO for the provision of expert advice on microbiological food safety risk assessment. To date, the JEMRA takes the form of a series of meetings of experts. It reviews and interprets existing microbiological risk assessments on a number of pathogen/commodities combinations identified, and evaluate the likely impact of different risk management options (FAO, 2001).

The integration of disease data and food data within the microbiological risk assessment framework will clarify linkages and cause–effect relationships. It will also provide a common framework for international collaboration, where models and examples from one country, or international models, can be used to guide the data generation and eventually the data use of other countries, making way for efficient global spread of evidence-based, transparent new food safety understanding. The basis for all of this is a common understanding of this new risk assessment tool and its use (WHO, 2000d; FAO, 2001).

One interesting new approach attempting to link the fraction of human salmonellosis cases to food commodities, uses a comparison of the relative fractions of the total number of laboratory confirmed human cases caused by different *Salmonella* sero- and phage-types to the corresponding *Salmonella*-types isolated in the various food sources (Anonymous, 2000c). Investigations into the epidemiology of *Salmonella* in the USA used only serotyping but was still able to tentatively link the outcome of pathogen-reduction programs for meat, poultry and eggs to the serotype distributions in humans (Olsen et al., 1987). Other investigations found important differences between serotype distributions of *Salmonella* isolates from food animals after slaughter and serotype distributions of isolates from man in the USA (Sarwari and Magder, 2001). Although this study could be said to raise questions about raw animal products being the primary source for human salmonellosis, the implications of differences in ecological behaviour and/or in virulence of different serotypes could also be questioned, while the importance of the relative fractions of salmonellosis with a nonmeat or a nonfood source were not dealt with directly. In general the use of new typing methodology to improve linkage capacity is an important new scientific area. Using such methodology and linking data through the use of more formal risk assessment methodology could make it feasible to broaden the 'relative isolate fraction' approach also to other foodborne pathogens, resulting in more efficient linkages between food and patients.

The development of an interdisciplinary approach acknowledging the need for direct interaction between surveillance and risk analysis systems is new in foodborne disease prevention in all countries. However, especially the situation in developing countries warrants a speedy development of this new direction. Most developing countries cannot afford building separate systems and should leap forward past the experience of noncollaboration between the disciplines in many developed countries. Thus, the development of new integrated systems should be specifically directed towards the needs of developing countries building upon the (limited) experience in the developed world.

7.4. Microbial ecology and risk

Part of the farm to fork microbiological risk assessment dealing with exposure assessment should also cover the implications of the ecology of the microorganisms in question in relevant habitats, be that in the environment, in production animals or in the production system. In this area, significant new knowledge have been developing over the last two decades; nevertheless, the implications of a number of these new findings are still not fully understood. While it is not the intention of this paper to present a comprehensive description of this area, two important subjects, where new understanding in microbial ecology can significantly improve risk reduction efforts, will be briefly discussed: stress response survival and biofilm ecology.

The suggestion by Colwell et al. (1985) that a physiological stage of *Vibrio cholerae* in water existed where the microorganism remained viable but could not be cultured set of a long line of research of this phenomenon for other bacterial species. It was soon realised that while the question of cell death versus survival intuitively seems simple, it is in reality very complicated in relation to microorganisms (Roszak and Colwell, 1987). It is generally accepted that bacteria in the environment exist in constant flux between short periods of growth and much longer periods of nongrowth. The bacterial regulation of starvation and other stress forms have been described intensively over the last decade. It has been found that many bacteria, among them *Escherichia*, *Salmonella* and *Vibrio* spp. can enter a resistant state upon starvation and other forms for stress (Siegele and Kolter, 1992). The suggested concept of 'viable but nonculturable' forms of microorganisms as a response to specific stress needs further investigation, but whether the phenomenon is a genuine physiological response or a reflection of the imperfection of our present detection methodology, the fact remains that our traditional quantitative, as well as qualitative, bacteriological measurements, could be seriously flawed. The potential impact of this needs consideration, also within the risk assessment framework.

Stress response is relevant for our understanding of the fate of pathogens both in relation to survival potential in the environment, but also directly in foods. Investigations into the survival of enterohemorrhagic *E. coli* in acidic foods has shown an ability of this microorganism to enhance survival under acid stress through the induction of physiological stress response (Buchanan and Edelson, 1999). It is likely that stress response mechanisms play a significant role in defining bacterial survival also relative to other food technology hurdles as well as to disinfectants, but again our present knowledge is limited. New in situ methodology as well as real-time monitoring of bacteria in food and under food production could present us with a new understanding in these areas.

In many types of environment, microorganisms attach to surfaces and produce extracellular polysaccharides, resulting in the formation of a biofilm. While biofilm formation has been studied for aquatic microorganisms for more than 70 years, more recent investigations in this area has shown implications which are certainly also relevant within the context of food safety. Biofilms are organized multicellular systems, which seem to be able to interact through signal systems, in effect enabling the community of microorganisms to induce certain phenotypic traits (Nilsson et al., 2001). It has been found that microorganisms in biofilms can find protection from the effect of disinfectants, such as chlorine (LeChevallier et al., 1988) and other antimicrobials. Interestingly, the biofilm related antibiotic resistance seem to depend on multicellular strategies in the biofilm (Stewart and Costerton, 2001).

Biofilm does of course not only exist in the environment, but is also very relevant in food production systems. In laboratory experiments, *S. typhimurium* and *E. coli* O157 has been found to increase over time in biofilm on stainless steel (Hood and Zottola, 1997). Investigations in food production plants shows that the *L. monocytogenes* contamination of final products often seem to originate from the processing environment (house strains) and not from raw material (Dauphin et al., 2001). Differences in growth behaviour of *L. monocytogenes* in biofilm as compared to planktonic growth has also been found

(Chae and Schraft, 2000). This could indicate that some food-borne pathogens have important niches for survival or growth in production biofilm.

In general, new, culture-independent, molecular techniques as well as in situ techniques for microbial detection, characterization and enumeration will improve our ability to study microbial ecosystems. The use of these methods open interesting perspectives related to population dynamics of microbial communities in foods and could form the basis for an improved understanding of the diversity of microbial communities in real life, including in our food. It is likely that such improvements in our ecological understanding are important prerequisites for continuously improved food safety.

7.5. Communication

Food safety is considered a complicated topic and it seems difficult for consumers to understand and extract a coherent message from what experts, regulators, producers etc. state on this subject. The confusion is in reality often caused by the inability of experts and regulators to explain and communicate even simple messages.

Risk communication is based on the exchange of information between regulators and interested parties, including the public in general. The most general objective of risk communication is to build consensus on the appropriate management of risk. Risk communication is a critically important aspect of risk analysis because safety is supposedly realized through a negotiation about the acceptability of risks by those who are the bearers of risk. Risk communication is the process by which this acceptance is established and maintained. Uncertainty is one of the most critical issues in risk communication and dealing with the meaning of uncertainty in scientific data is a very important area for both scientists and regulators. Nevertheless, most information or communication efforts within present food safety systems have largely avoided reference to this important area, and its implications for differences between national food safety decisions, even when the underlying scientific data evaluated is the same.

The involvement of all stakeholders in the risk management process is likely to rely on efficient future risk communication. Unfortunately, this area is clearly the least developed within the risk analysis framework.

8. The WHO global food safety strategy

Realizing the problems of the past and the need for increased WHO involvement in food safety in the future, the Executive Board of WHO has at its meeting in January 2002 endorsed a WHO Global Food Safety Strategy, the main areas of which are:

8.1. Surveillance of foodborne diseases

WHO will facilitate the strengthening of foodborne disease surveillance systems and their linkage to food contamination monitoring programmes. There is a need for a more thorough understanding of food as a risk factor and an urgent need to link the pathogens in the food and the pathogens in the patients in order to guide prevention.

8.2. Improving risk assessments

WHO, in collaboration with FAO, will develop tools for appropriate risk assessment. FAO/WHO expert groups will develop assessments to serve as the basis for international standards and guidelines as well as national food regulations or other initiatives. Data from the production and processing sector will hopefully provide an important additional input in this area.

8.3. Safety of new technologies

WHO will promote a holistic approach to the production and safe use of foods derived from new technology. There is a need to develop a framework for evaluation including safety considerations, health benefits, environmental effects and socioeconomic consequences of genetically modified foods. The production sector should play an important role in the interactive communication of benefits and risks of new technologies.

8.4. Public health role in Codex

WHO seeks greater involvement of the health sector in the development of Codex standards, guidelines and recommendations. WHO will assist and support the effective participation of developing countries in the work of Codex. WHO will also support a thorough review of the Codex system, hopefully encouraged with input and new thoughts from consumers as well as producers.

8.5. Risk communication

The results of risk analyses should be communicated in a readily understandable form. WHO will support the development of communication methods for fostering dialogue and participation of stakeholders, including producers and consumers, in the process.

8.6. International cooperation and capacity building

WHO will work for the coordination of food safety also at the international level. WHO will formulate regional food safety strategies acknowledging specific regional needs. Donor support will be needed to prioritize food safety in public health in developing countries. Agricultural producers, recognizing their inherent responsibility in the area, should support data collection, risk assessment and capacity building in support of a new food safety focus.

9. Final words

Today food safety is one of WHO's top eleven priorities and our member states have adopted a strongly worded resolution that recognizes food safety as an essential public health function (WHO, 2000a).

There are a lot of interesting challenges in the area of food safety, there is now a time for change. The realization of problems have spurred a new wave of solutions. However, these solutions will not materialize without support from all parts of the food production and consumption chain.

These considerations result in a call for more systematic and aggressive steps to be taken to significantly reduce the risk of microbiological foodborne diseases. This is a strong and clear call that cannot be denied. Dealing with it is without any doubt one of the major challenges for the 21st century in regard to food safety.

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