REVIEW ARTICLE
A brief review of foodborne zoonoses in China

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SUMMARY

Foodborne zoonoses have a major impact on public health in China. Its booming economy and rapid socioeconomic changes have affected food production, food supplies and food consumption habits, resulting in an increase in the number of outbreaks of foodborne zoonoses. Both emerging and re-emerging foodborne zoonoses have attracted increasing national and international attention in recent years. This paper briefly reviews the main foodborne zoonoses that have had a major impact on public health over the last 20 years in China. The major causative microorganisms, including foodborne bacteria, parasites and viruses, are discussed. The prevention and control of foodborne zoonoses are difficult challenges in China. The information provided here may aid the development of effective prevention and control strategies for foodborne zoonoses.

Key words: Bacteria, China, food safety, foodborne zoonoses, parasites, viruses.

INTRODUCTION

Foodborne zoonoses are defined as infections and diseases that are transmissible between animals and humans via foodstuffs [1]. They are caused by foodborne bacteria, parasites, viruses and prions, and have a major impact on global public health. In industrialized countries, up to 10 % of the human population may annually suffer from foodborne zoonoses [2]. In China, the number of outbreaks of foodborne disease and the number of individuals affected has increased in the last two decades. During 1994–2005, 12 687 incidents of foodborne disease were reported to the Chinese authorities, in which 289 380 individuals were affected and 2297 individuals

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died [3]. Of the outbreaks for which the aetiology was determined, 40–50 % were caused by predominantly zoonotic microorganisms [4, 5]. This paper briefly reviews the main foodborne zoonoses that have had a major impact on public health over the last 20 years in China. The causative microorganisms include foodborne bacteria, parasites and viruses.

FOODBORNE BACTERIAL ZOONOSES

In China, foodborne bacterial diseases accounted for more than 28·25 % of all cases of foodborne disease during 1994–2005, and more than 42·75 % of cases annually [3]. Most bacteria that play a role in foodborne diseases have a zoonotic origin, with reservoirs in food animals. *Salmonella* and *Campylobacter* account for over 90 % of all reported cases of bacteria-related food disease worldwide [6]; however, in China,

cases caused by *Campylobacter* are rare, although the rate of detection of *Campylobacter* is approximately 30% in fowl meat and milk in China [7]. Of the 57 612 cases reported in China during 1994–2005, *Salmonella* was the most frequently identified agent, accounting for 22·16% of illnesses, followed by *Vibrio parahaemolyticus* (18·73%), *Proteus* (11·56%), a mixture of bacteria (11·2%) and *Bacillus cereus* (9·97%) [3]. In this section, we review some of the most significant foodborne bacterial zoonoses in China, some of which have re-emerged.

Escherichia coli O157:H7 infection

E. coli O157:H7 is the main serotype of enterohaemorrhagic *E. coli* and a cause of foodborne zoonoses. Infection with *E. coli* O157:H7 often leads to bloody diarrhoea, haemorrhagic enteritis, haemolytic uraemic syndrome and acute kidney failure, especially in children. *E. coli* O157:H7 became well known to the public because of two outbreaks, which resulted in four fatalities in 1993 in the USA and over 10 fatalities in 1996 in Japan [8].

E. coli O157:H7 was first reported in 1990 in China, where five strains were isolated from 486 stool specimens collected during 1986–1988 from patients with diarrhoea in Jiangsu province [9]. An epidemiological survey revealed that the proportion of haemorrhagic colitis caused by *E. coli* O157:H7 was 0·98–5·89% in Xuzhou in Jiangsu province in June 2000, and in 27 isolates of *E. coli* O157:H7, 13 strains were identified as being *Shiga* toxin positive [10]. In addition to infecting humans, *E. coli* O157:H7 was also detected in food animals. The overall detection rate of *E. coli* O157:H7 by an immunomagnetic separation technique in 1767 faecal samples collected from pigs, chickens, sheep and cattle in Jiangsu province in 1999 was 9·62%, and 56·47% of these strains carried the *SLT2*, *eaeA* and *Hly* toxin-encoding genes [11]. *E. coli* O157:H7 was not the dominant serotype of *E. coli* in food animals in China. A survey of the serotype distribution of *E. coli* in food animals in Hefei area of Anhui province indicated that *E. coli* O157:H7 was not detected by a slide agglutination test in 46 strains of *E. coli* isolated from diseased pigs and chickens, where serotype O127:K63 was most common, accounting for 33·33% (13/39) of identified isolates, followed by O142:K86 (15·38%), O125:K70 (12·82%), O111:K58 (10·26%) and O114:K90 (7·69%) [12]. The Chinese government has maintained a national network for the detection of *E. coli* O157:H7 since 1997, which involves over 30 public health laboratories in several provinces and municipalities [13].

Salmonellosis (*Salmonella* infection)

Salmonellosis is a foodborne zoonosis caused by *Salmonella*, which infects humans and some warm-blooded animals, causing symptoms ranging from mild abdominal discomfort, to dehydration and vomiting, to death [14]. Many *Salmonella* infections of humans are due to ingestion of contaminated food of animal origin. More than 2500 serotypes of *Salmonella* have been identified to date, with over 200 serotypes being detected in China [15, 16]. China has submitted 268 strains to the WHO Global Salm-Surv Country Databank, a valuable resource for international *Salmonella* surveillance [17]. *Salmonella* contamination in food of animal origin is relatively common in certain provinces of China. About 54% (276/515) of chicken, 31% (28/91) of pork, 17% (13/78) of beef and 20% (16/80) of lamb samples collected from markets in Shaanxi province during 2007–2008 were found to be positive for *Salmonella*, serotype *S*. Enteritidis was most common, accounting for 31·5% of the identified isolates, followed by *S*. Typhimurium (13·4%), *S*. Shubra (10·0%), *S*. Indiana (9·7%), *S*. Derby (9·5%) and *S*. Djugu (7·0%) [18]. The contamination of food with *Salmonella* causes occasional outbreaks of *S*. Enteritidis. Liu *et al*. reported a massive outbreak of *S*. Enteritidis linked to *Salmonella*-contaminated eggs, where 197 of about 2000 workers became ill after eating cakes that had been in contact with raw eggs contaminated with *Salmonella* [19].

Vibrio parahaemolyticus infection

V. parahaemolyticus, a common bacterium in marine and estuarine environments, infects humans and is commonly associated with the consumption of raw or contaminated seafood, particularly molluscs, leading to clinical symptoms of acute gastroenteritis to septicaemia. *V. parahaemolyticus* accounted for a significant number of outbreaks (19·5%) and cases (18·73%) of foodborne illnesses during 1994–2005 in China [3]. The prevalence in suspected food samples of food poisoning outbreaks in Jiangsu province was 35·9%, while 24·9% of faecal samples from patients and outpatients with food poisoning were positive for *V. parahaemolyticus* [20]. An epidemiological survey

indicated that 47·2% of aquatic products collected from retail markets and restaurants in Jiangsu province were positive for *V. parahaemolyticus*, with 8·5% and 1·5% of strains carrying the *tdh* and *trh* virulence genes, respectively [20]. Yang *et al.* reported that the isolation rates of *V. parahaemolyticus* from fresh, frozen/iced, dried, and salted seafood samples were 33·4%, 14·9%, 4·6%, and 4·3%, respectively, in Jiangsu province and Shanghai city [21].

Campylobacteriosis (*Campylobacter* infection)

Campylobacteriosis is an infection caused by the *Campylobacter* bacterium, most commonly *C. jejuni*, which has been recognized as an important zoonotic pathogen since the 1980s throughout the world. *C. jejuni* is found in the intestines of many wild and domestic animals. Human infection can be acquired via consumption of contaminated food and meats, especially chicken. In China, *C. jejuni* is most frequently detected in poultry with an average isolation rate of up to 18·61% and a flock contamination rate of 86·67%. The average incidence of *C. jejuni* in cattle, milk cows, heifers, and diarrhoea patients was 7·77%, 5·02%, 8·70%, and 4·84%, respectively, in Jiangsu province [22]. Yang *et al.* reported that 30·6% of chicken meat, 27·3% of milk, and 13·6% of water samples tested positive by a real-time polymerase chain reaction (PCR) assay for *C. jejuni* [7]. *C. jejuni* is associated with the development of Guillain–Barré syndrome (GBS) in humans. An outbreak with 36 cases of GBS was reported in Jilin province in 2007, serological and molecular analysis indicated that this outbreak was preceded by *C. jejuni* infection [23].

In addition to *C. jejuni*, *C. coli* is also a causative agent of campylobacteriosis. Sun *et al.* reported that the prevalence of *Campylobacter* in chicken, duck, rabbit meat, pork, and beef collected from retail markets in Shenyang city were 94%, 96%, 97%, 31%, and 35%, respectively, and in 525 isolates of *Campylobacter*, 217 (41%) strains were identified as being *C. coli* by PCR analysis [24]. *C. coli* has been isolated from broiler chickens and pigs, with an isolation rate of 6·9% and 16·6%, respectively, in Shandong province [25, 26].

Yersiniosis (*Yersinia enterocolitica* infection)

Yersiniosis is a zoonotic disease caused by *Y. enterocolitica*, a genus of Gram-negative rod-shaped bacteria of the family Enterobacteriaceae. Acute *Y. enterocolitica* infection causes diarrhoea, abdominal pain, fever and a number of other symptoms. *Y. enterocolitica* has a broad animal reservoir, with pigs being the most common source of infection for humans. *Y. enterocolitica* infection can be acquired by eating contaminated food, especially raw or undercooked pork products, and by drinking contaminated unpasteurized milk or untreated water.

In China, two outbreaks of *Y. enterocolitica* causing more than 500 infections were reported as early as the 1980s. *Y. enterocolitica* is distributed in a diverse range of animals in China, with strains being isolated from more than 10 kinds of animals including pigs, cattle, goats, dogs, and mice [27]. An epidemiological survey showed that 416/1295 (32%) strains isolated from diarrhoea patients, livestock, poultry, wild animals, insect vectors, food and the environment, were pathogenic. The main serotypes of Chinese isolates are O:3 and O:9, which are distributed mostly in the cold northern areas, whereas some serotype O:3 strains are detected in the warm southern areas [28].

Listeriosis (*Listeria monocytogenes* infection)

Listeriosis is a potentially serious infection caused by *L. monocytogenes*, a Gram-positive motile bacterium. Animals can carry *L. monocytogenes* and contaminate foods of animal origin. Human infection can be acquired via ingestion of food products contaminated with *L. monocytogenes*. An epidemiological survey indicated that the prevalence of *L. monocytogenes* in raw meat, fish, and poultry products collected from retail markets in Yangzhou city was 4·83%, 2·00%, and 1·55%, respectively [29]. Yan *et al.* reported that contamination by *L. monocytogenes* was detected in 4·13% (90/2177) of food samples (raw meats, cooked meats, rice products, bean products, seafood, vegetables) collected from nine cities in northern China during 2005–2007, with an average isolation rate of 6·28% (46/733) in raw meat products. The isolates of *L. monocytogenes* belonged to five serotypes (1/2a, 1/2b, 1/2c, 4b, 3a), with 1/2a being the dominant serotype (48·88%) [30].

Streptococcus (Str.) *suis* infection

Str. suis is a peanut-shaped, Gram-positive bacterium that is carried by pigs and generally does not cause illness, but can occasionally cause disease. Thirty-five serotypes have been identified and serotype 2 is the dominant pathogenic serotype in swine and humans.

Infection of humans and pigs with *Str. suis* causes meningitis, septicaemia, endocarditis, arthritis and septic shock. Human infection can be acquired through exposure to *Str. suis*-contaminated pigs, pork or pork-derived products. The number of *Str. suis* infections in humans has increased significantly in recent years in South East Asia. Two massive outbreaks occurred in 1998 and 2005 in China. In the 2005 outbreak, a total of 215 cases of human *Str. suis* infection, 66 of which were laboratory confirmed, were reported in Sichuan province. All infections occurred in backyard farmers who were directly exposed to infection during the butchering process of pigs that had died of unknown causes. Sixty-one (28%) of the farmers exhibited streptococcal toxic shock syndrome and 38 (62%) died [31]. Analysis of the serotype of 421 strains of *Str. suis* that were isolated from clinically healthy sows from 10 provinces of China showed that the most common serotype was type 9 (26·6%), followed by type 3 (23·5%), type 7 (15·7%) and type 2 (7·4%) [32].

FOODBORNE PARASITIC ZOONOSES

Foodborne parasitic zoonoses that are caused by helminths and (or) protozoans through the consumption of infected or contaminated meat and/or fish represent a significant health problem in China, where about 150 million people suffer from foodborne parasitic zoonoses and more people are at risk [33]. The second national survey on the current status of important parasitic diseases in the human population, which was carried out from June 2001 to 2004, indicated that the total number of people suffering from clonorchiasis, trichinellosis, paragonimiasis, and angiostrongyliasis had increased compared to the first national survey carried out between 1988 and 1992. Some of these conditions cause significant public health problems [33].

Clonorchiasis [*Clonorchis (Cl.) sinensis* infection]

Clonorchiasis is one of the major parasitic zoonosis in China, and is caused by *Cl. sinensis*. Human and animal reservoir hosts (dogs, pigs, cats, rats) acquire the infection via the ingestion of raw fish or shrimps containing infectious metacercariae of *Cl. sinensis*. It is estimated that 35 million people are infected globally, of which 15 million reside in China, with the largest incidence (5·5 million) in Guangdong province [34]. An epidemiological survey of the prevalence of *Cl. sinensis* in human populations in Hengxian county of Guangxi province indicated that 31·6% (491/1552) of faecal samples examined by the Kato-Katz thick smear technique were positive for *Cl. sinensis*, showing an increase from 18% to 31·6% in the past decade [35]. In the Shenzhen area of Guangdong province, 4·75% of people and 1·15% of snails examined were positive for *Cl. sinensis*, and the average infection rate in 15 species of freshwater fish was 16·97% [36]. The increased prevalence of clonorchiasis in humans was proposed to be related to factors such as unhygienic practices, poor knowledge, inappropriate farming/fishery practices and eating raw fish [36].

Trichinellosis (*Trichinella* infection)

Trichinellosis is caused mainly by the consumption of raw or undercooked pork or wild game that is infected with the larvae of a species of the *Trichinella* genus. Pork infected with *T. spiralis* is the main source of human infection, while dog meat contaminated with *T. native* also contributes to infections in China [37]. Swine trichinellosis has been reported in 26 provinces of China, with a prevalence rate varying from 0·0001% to 34·2%. Transmission to pigs by the consumption of contaminated garbage is the main factor in the epidemiology of swine trichinellosis. The rate of prevalence of *T. spiralis* in pigs varied from 1·98% to 15·06% in certain provinces and serves as an important reservoir in the domestic cycle of trichinellosis [38]. *Trichinella* larvae were detected in 0·29–5·6% of pork, 1·4% (3/215) of mutton and 2·1% (1/47) of beef sold at markets in certain provinces [39]. In addition to pork, dog meat has become an important source of *Trichinella* infection for humans. The average prevalence of the infection in dogs was 16·2%, ranging from 1·2% to 44·8%, with the highest prevalence located in northeast China. An outbreak caused by consumption of contaminated dog meat has been reported [40]. *Trichinella* infection has also been recorded in wildlife including wild rats, foxes, bears, wild boar, weasels, raccoon dogs, muntjak and bamboo rats [39].

Cysticercosis and taeniasis (*Taenia* infection)

Cysticercosis and taeniasis are, respectively, parasitic infections with the larval and adult stages of taeniid tapeworm. Human infection can be acquired via eating inadequately cooked pork that contains the larval stage of *Taenia (Ta.) solium*. *Ta. solium* is cyclically

transmitted between humans and pigs, with pigs being the natural intermediate host. In China, cysticercosis was prevalent in northeastern areas several decades ago. Despite efforts to reduce transmission of cysticercosis over the last 30 years, it is still emerging as a serious public health problem in certain areas of China [41]. *Ta. solium* infection is particularly prevalent in rural areas of 29 provinces, especially in minority populations, such as the Yi, Bai and Miao groups, where raw or undercooked pork is consumed, and scavenging pigs have access to human faeces [41]. A survey of porcine cysticercosis performed via post-mortem inspection in nine districts of Guizhou province indicated that 328/4292 (7·6%) pigs harboured *Ta. solium* cysts and that 357/2599 (13·7%) samples collected from pigs were serologically positive for *Ta. solium* [42]. In Liangshan prefecture of Sichuan province, porcine cysticercosis was highly endemic, with the prevalence in pigs ranging from 3·3% to 10·4%, with the highest rates being 25–30% [43].

In addition to *Ta. solium*, *Ta. saginata* is also a causative agent for human *Taenia* infection. Human infection can be acquired via eating inadequately cooked beef infected with the larval form (*Cysticercus bovis*) of *Ta. saginata*. *Ta. saginata* infection is endemic in western China [44]. A survey of the prevalence of taeniasis/cysticercosis in Tibetan populations in Yajiang county of Sichuan province, where undercooked beef is consumed habitually, indicated that *Ta. saginata* was the dominant species causing human infection, where 30·5% of individuals reported proglottid expulsion (anamnesis) and 18/21 proglottids were identified as *Ta. saginata* by PCR [45]. Shen *et al.* reported that *Cysticercus bovis* was detected in slaughterhouse cattle with prevalence rates ranging from 0% to 2·56% in Yili prefecture of Xinjiang uyghur autonomous region during 1991–2006 [46].

Angiostrongyliasis (*Angiostrongylus cantonensis* infection)

A. cantonensis is a nematode parasite that causes angiostrongyliasis in humans. Snails and slugs are intermediate hosts. Of 32 wild molluscs screened for *A. cantonensis*, 22 (68·8%) were found to harbour the parasite in China. The highest rate and intensity of infections were recorded in giant African land snails (*Achatina fulica*), followed by slugs (*Vaginulus* spp.) and *Pomacea canaliculata*. Terrestrial snails and slugs showed higher rates and intensities of infection than freshwater molluscs [47]. Humans are incidental

hosts of *A. cantonensis*. Human infection can be acquired mostly by consumption of raw or undercooked snails or slugs that contain the third-stage larvae of *A. cantonensis*. The first case of human angiostrongyliasis in China was diagnosed in 1984, and the number of cases has sharply increased during the past decade [47]. A large outbreak of *A. cantonensis* infection occurred in Beijing in 2006, where 160 people who had a history of eating raw freshwater snails became ill, 100 of whom were hospitalized. Of these patients, 81 were diagnosed with angiostrongyliasis [48].

FOODBORNE VIRAL ZOONOSES

In contrast to foodborne bacterial and parasitic zoonoses, only a few foodborne viral zoonoses have been identified. Although many different types of viruses, such as coronavirus and rotavirus, are present in the intestinal tracts of animals and are shed into the environment via faeces, awareness of the significance of these viruses with respect to food safety is generally poor. Severe acute respiratory syndrome (SARS) coronavirus spread to humans through the preparation and consumption of food animals, and the consumption of duck blood resulted in the infection of humans with H5N1 avian influenza virus. These cases have raised the question of whether foodborne introduction could be one of the routes by which these new viral diseases enter the human population [49].

Hepatitis E, caused by hepatitis E virus (HEV), is considered a foodborne viral zoonosis. Pigs, boars and deer have been identified as reservoirs, and their flesh and entrails as vehicles of HEV transmission to humans [50]. Hepatitis E infection of humans was first recognized after a large epidemic of non-A, non-B hepatitis in the Xinjiang region of China in 1986 [51]. Serological surveillance performed by an enzyme-linked immunosorbent assay (ELISA) to monitor the prevalence of HEV antibodies in animals revealed that 82·5% of sows, 55·7% of slaughterhouse pigs, 24% of goats, 16·3% of horses, 17·8% of pet dogs, 6% of cows, 12·8% of ducks, 4·4% of pigeons and 1·9% of chickens were positive for these antibodies in eastern China [52]. Genotypes 3 and 4 of HEV are the most common in pigs in China. Swine and human HEV strains show extremely close genetic relatedness, which supports the hypothesis that hepatitis E is zoonotic in China [53].

Hepatitis A is also considered a foodborne viral zoonosis, which is caused by hepatitis A virus (HAV),

a faecal–oral pathogen. The transmission between individuals is associated with HAV-contaminated food and water. Shellfish contaminated with HAV is particularly notorious as a vehicle for the transmission of HAV. A major outbreak of hepatitis A, associated with consumption of HAV-contaminated raw clams, occurred in Shanghai city in 1988, in which over 300 000 cases were reported, 47 (0·015%) of which were fatal [54]. A total of 136 field oyster samples collected from seafood markets in Guangdong province in 2007 were screened by RT–PCR, seven (5·1%) of which were positive for HAV [55]. A survey of the contamination of HAV in aquatic products indicated that 13·83% of samples collected from aquatic product markets in Shanghai during 2002–2005 tested positive by an antibody capture RT–PCR for HAV [56].

CONCLUSION

Since the transition to a market economy, the booming economy and rapid socioeconomic changes in China have affected food production, food supplies and food consumption habits. For example, the populations of livestock have increased exponentially in the last two decades. More Chinese have become used to eating raw or lightly cooked food and to demanding exotic foods, such as Japanese *sashimi* (fresh raw seafood). These changes have resulted in an increase in the number of outbreaks of foodborne zoonoses. However, the burden of disease caused by foodborne zoonotic pathogens remains largely unknown in China.

Foodborne zoonotic pathogens have developed efficient and effective strategies to exploit food as a vehicle for transmission from animals to humans. In addition, previously unknown foodborne zoonotic pathogens are constantly emerging. Therefore, the effective prevention and control of foodborne zoonoses presents a significant challenge in China, a country with more than 1·3 billion people of 56 nationalities with diverse food cultures, and millions of pigs and billions of poultry raised under a range of sanitary conditions. In the fight against foodborne zoonoses, efficient surveillance systems, and risk assessment and management systems should be established. Moreover, constructive dialogue and collaboration between public health workers, veterinarians and food-safety experts is essential to develop effective prevention and control strategies.

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