Pathogens of Future Concern

IRENE V. WESLEY *

"Chance favors the prepared mind"

Louis Pasteur

Examination of the factors contributing to the emergence of newly-recognized pathogens will allow us 1) to determine the risk of their emergence, 2) to predict the extent of their dissemination, and 3) to design intervention strategies to either avert or dampen their impact. Key factors contributing to the emergence and reemergence of infectious diseases in humans and animals (Vidaver, 1997, Table 1) and examples of emerging agents (Table 2, Shadduck et al., 1996; Nettles, 1996) have been summarized. The information gleaned from the studying patterns of emergence will provide us with the clairvoyance to examine potential human foodborne pathogens of future concerns.

Multiple antibiotic resistant *Salmonella typhimurium* DT 104 is a pathogen of significance to livestock and humans. It is unusual in that it is resistant to at least 5 antibiotics: ampicillin (A), chloramphenicol (C), streptomycin (S), sulfonamides (Su), tetracycline (T). In 1984, the first outbreak of *Salmonella typhimurium* definitive type (DT 104) was reported in the UK in dairy cattle (for a review see Morbidity and Mortality Weekly Report, April 11, 1997). By 1994, 64% (290 of 450) all *Salmonella* recovered from cattle in Scotland were *S. typhimurium* DT 104. In the UK, dairy and beef cattle are equally susceptible. Based on a study of 656 cases and 505 control herds, risk factors contributing to outbreaks in the UK dairy herds included purchase of replacement stock from dealers rather than directly from another farm, introduction of animals onto farms without a quarantine period on the new premises, housing new calves in sick pens without appropriate disinfection, presence of wild birds and cats on the premises, especially if given access to feed stores, and failure to vaccinate (Evans and Davies, 1996). Newborn calves (13%) and newly calved cows (4%) are especially susceptible. Bloody diarrhea and mortality rates of up to 40% especially in the young animals occur. Animal infection can be transmitted to humans (Fone et al., 1994). In the UK 20% of the affected farms reported human illness (Evans and Davies, 1996). Contact with cattle, consumption of contaminated chicken, pork sausage and meat pastes were risk factors for *S. typhimurium* DT 104 in the UK (Wall, 1996). Human illness following consumption of contaminated beef has been documented (Davies et al., 1996). The emergence of *Salmonella* DT 104 with its multiple antibiotic resistance pattern (ACSSuT) may be attributed to changes in agricultural practices. Trimethoprim has been used to treat veterinary cases of DT 104. Between 1990 and 1995, resistance to trimethoprim has increased in human cases of *Salmonella* DT 104 from 0% to nearly 27% (Threlfall, 1996). In the US, multiple drug resistance for *S. typhimurium* has risen from 7% in 1990 to 28% in 1995 when 83% (25 of 30) *of S. typhimurium* resistant-type ACSSuT isolates were phage typed as DT 104. In the US, 24% of the *Salmonella* isolates reported to CDC in 1995 were *typhimurium*. Although the number of *S. typhimurium* isolated in the US has risen only slightly, the increase in those which show multiple drug resistance has risen disproportionately. In the Pacific Northwest, prior to 1986, none of 44 *S. typhimurium* cattle isolates was DT 104. Since 1992, 64% of the 51 isolates examined showed multiple drug resistance (Besser et al., 1997). As in the UK, the appearance of *Salmonella* DT 104 in US dairy herds has also resulted in animal and human disease. The emergence of *S. typhimurium* DT 104 strains indicates this as a microbe of imminent public health concern.

Tuberculosis (TB) in humans and animals was held in check, but reappeared during the late 1980's and 1990's. In livestock, the movement of cattle across the U.S.-Mexican border may have fueled the resurgence of bovine tuberculosis which has spilled over to the deer population. Factors which contributed to its reintroduction include an outdated deficient diagnostic test for cattle, lingering TB infections in a few herds scattered throughout the US, rapid growth of the farm deer industry, absence of adequate treatment for tuberculosis in deer, lack of an effective vaccine, and an inadequate infrastructure–namely state and federal fiscal constraints resulting in a markedly reduced surveillance program (Nettles 1996; Shadduck et al., 1996).

*Irene V. Wesley, National Animal Disease Center, Agricultural Research Service, U.S. Department of Agriculture, Ames, Iowa 50010.

Reciprocal Meat Conference Proceedings, Volume 50, 1997.

TABLE 1. Reasons for Increase in Emerging and Reemerging Infectious Diseases (adapted from Vidaver, 1997).

Population shifts
Population growth
Changes in human behavior
Changes in agricultural and food practices
Urbanization
Crowding
Changes in ecology and climate
Microbial evolution
Modern medicine
Modern travel
Modern trade
Animal migration
Animal relocation
Inadequacy of public infrastructure
Improved surveillance

TABLE 2. Emerging and Reemerging Infectious Diseases (adapted from Nettles, 1996).

Bovine and cervid tuberculosis
Brucellosis in bison and elk
Velogenic Newcastle Disease
Bovine spongiform encephalopathy
Chronic wasting disease
Human microsporidiosis
Sarcocystis falcutula in horses
Cryptosporidum water-borne outbreaks
Salmonella typhimurium 104
C. jejuni and Guillain–Barre syndrome

The emergence of bovine spongiform encephalopathy (BSE) in the UK in 1986 has been traced to changes in human behavior, as reflected in altered rendering practices (see review by Moon, 1995). Although the origin of BSE is not known, BSE may have arisen from scrapie which has become adapted to cattle. In the early 1980's, changes were made in the rendering process which may have permitted the scrapie agent to survive and be transmitted in by–products fed to cattle. The BSE epidemic involved the death of more than 150,000 cattle and loss of consumer confidence in the safety of the meat supply (Shadduck et al., 1996). In the US, there is concern regarding other transmissible spongiform encephalopathies (TSE) in livestock and the perceived potential of human infection.

Verocytotoxin–producing *E. coli* (VTEC) of serotype O157:H7 is an important agent of foodborne disease in humans worldwide. The emergence of hemolytic uremic syndrome (HUS) in humans may have resulted from microbial evolution as well as changes in dietary habits in the U.S. Although the origin is still unknown, the rampant spread of *E. coli* O157:H7 in Japan in 1996 may have been facilitated by urban crowding. From May to October 1996, 18 outbreaks were reported in Japan, involving 8422 patients. Eight of the 18 outbreaks occurred in primary and secondary schools. The largest outbreak in Sakai City involved 5700 patients (Takeda, 1997). While the majority of research has targeted O157:H7, other serotypes of VTEC can be associated with human disease. A concurrent outbreak of *E. coli* O118:H2 involving 247 children was also reported in Japan in 1966. Johnson et al. (1995) estimated that nearly 25% of HUS cases are caused by non–O157 :H7 *E. coli* strains. That many of the 100 serotypes of VTEC in cattle are also seen in humans suggests closer examination of these agents as pathogens for future concern (Johnson et al., 1995).

Campylobacter, *Helicobacter*, and *Arcobacter* are closely related fastidious, gram-negative bacteria which are motile by means of flagella (Vandamme et al., 1991) . In the U.S., *Campylobacter jejuni* is now regarded as the most common cause of human bacterial enteritis with 2,100,000 cases reported annually at a cost of nearly $1 billion. Transmission of *C. jejuni* to humans occurs via consumption of contaminated undercooked poultry, water, raw milk, milk which has been contaminated after pasteurization, and shellfish. The most common antecent of Guillain–Barre syndrome is a recent infection with *C. jejuni* (Rees et al., 1995). Guillain–Barre syndrome may be attributed to a number of factors, including microbial evolution and an inappropriate host immune response to bacterial antigens. Host antibodies against *C. jejuni* may cross react with gangliosides of the human nervous system causing paralysis. The Centers for Disease Control have targeted reduction of *C. jejuni* cases (per 100,000 population) in the US from 50 in 1987 to 25 by 2000. Reducing levels of *C. jejuni* in the food supply and interrupting the cycle of transmission to humans will avert this rare neurological sequel.

Helicobacter pylori is the most common chronic bacterial infection in man and is the major etiologic agent for chronic active gastritis (Blaser, 1993 ; Goodwin and Worsley, 1993). It has been detected in water, but not in foods. *Arcobacter* spp. have been associated with cases of human enteritis and enteritis and abortion in livestock. *Arcobacter* spp. have been found in water, cattle, swine, poultry, and ground pork products. Because of their phylogenetic proximity, transmission mechanisms described for *C. jejuni* may be applicable to *Helicobacter* and *Arcobacter*. Herein we review the evidence for considering *Helicobacter* spp. and *Arcobacter* spp., especially *A. butzleri*, as human foodborne pathogens of future concern.

Helicobacter

Members of the genus *Helicobacter* colonize humans and animals, and cause enteritis and gastritis. *Helicobacter pylori* is present in 95% of duodenal and in 70 to 80% of human gastric ulcer cases as well as in clinically healthy individuals, including family members of patients (Goodman and Correa, 1995). The animal hosts from which other *Helicobacter* species have been cultured are summarized in Table 3. Knowing its occurrence in water, animals and

TABLE 3. Summary of *Helicobacter* species and host distribution.

Bacterium	Source	Target Organ
Helicobacter pylori	Human	Gastric mucosa
Helicobacter acinomyx	Cheetah	Gastric mucosa
Helicobacter bilis	Mouse	Bile, intestine, liver
Helicobacter bizzozeroni	Canine	Stomach
Helicobacter canis	Dog, humans	Intestine
Helicobacter cholecystus	Hamsters	Gall bladder, Intestine
Helicobacter cinaedi	Hamsters, human	Intestine
Helicobacter felis	Dogs, cat	Gastric mucosa
Helicobacter fennelliae	Human	Intestine
Helicobacter helmannii	Humans, mice, pigs	Gastric mucosa
Helicobacter hepaticus	Mouse	Intestine
Helicobacter muridarum	Rat	Stomach, caecum
Helicobacter mustelae	Ferret	Stomach
Helicobacter nemestrinae	Monkey	Gastric mucosa
Helicobacter pametensis	Pig, tern	Intestine
Helicobacter pullorum	Poultry, humans	Intestine
Helicobacter rappini	Dogs, humans, sheep, mice	Intestine, reproductive tract
Helicobacter trogontum	Rat	Intestine
Helicobacter westmeadii	Humans	Unknown

food would be beneficial to determining if *H. pylori* is a potential human foodborne pathogen.

Serological Evidence for *H. pylori* Infection

Serological assays or blood tests are a rapid means of screening for *Helicobacter* infection. However, the accuracy of a serological test is dependent upon its specificity as demonstrated by lack of cross-reactivity with other bacteria, especially those within the genus Helicobacter. This is important when conducting serosurveys or blood tests of livestock. Most serosurveys rely on enzyme-linked immunosorbent assays (ELISA). The ELISA tests use a variety of antigen preparations and thus may vary in specificity.

Antibodies to *H. pylori* reflect infection status. Antibody titers peak 4 to 6 weeks after infection and decline shortly after the microbe has been eliminated following drug intervention (Goodwin and Worsley, 1993). Serosurveys, which measure infection based on blood test results, have been used to gauge the prevalence and thus identify risk factors for human infection with *H. pylori* (Goodman and Correa, 1995). In general, antibody titers are highest in individuals from rural settings and in populations of low socioeconomic status (Goodman and Correa, 1995; Goodwin and Worsley, 1993; Talley and Noack, 1993).

Field studies have shown that antibodies are most frequently found in individuals living in developing countries, where antibodies in excess of 50% of the population have been recorded (Goodwin and Worsley, 1993). In contrast, antibodies are found in less than 50% of the population living in industrialized countries such as Australia, the U.S., and France (Talley and Noack, 1993). Seropositivity, or a positive blood test for *H. pylori*, develops early in life when hydrochloric acid secretions, immune competency, and gastrointestinal flora have not attained adult levels. The immaturity of these natural defense mechanisms may facilitate colonization of *H. pylori*. Seropositivity increases with age. After childhood, the annual rate of acquiring new infections, as determined by antibody tests, varies from 0.3 to 0.6% in industrialized nations and up to 1% in developing countries (Goodman and Correa, 1995). The high titers observed in older adults may reflect diminished HCl activity and the cumulative effect of lifetime exposure.

Mechanisms of Transmission

Routes of transmission which have been proposed for *H. pylori* include: a) fecal-oral spread, b) oral-oral spread via salivary secretions, c) pet-to-human as well as human-to-pet transmission, and d) ingestion of contaminated foods and water (Goodman and Correa, 1995).

Helicobacter pylori has been detected in human feces either by culture (Gibson et al., 1995) or by polymerase chain reaction (PCR). Viable *H. pylori* were recovered from the feces of 9 of 23 randomly selected children, aged 3 to 27 months, from a Gambian village with a high prevalence of *H. pylori* infection. Thus, fecal-oral transmission may be important in the spread of infection in developing countries (Goodman and Correa, 1995).

Helicobacter pylori has been isolated from dental plaque and from the surface of the buccal cavity (Banatvala and Feldman, 1993; Nguyen et al., 1995), which suggests that infection could be transmitted by saliva. The evidence to support this view is also based on the higher prevalence of *H. pylori* infection among infants of African mothers who chewed their food prior to feeding it to their child than in

TABLE 4. Summary of *Arcobacter* Species and Host Distribution.

Bacterium	Source	Target Organ
Arcobacter butzleri	Humans	Intestine
	Livestock	Placenta, Fetus
Arcobacter cryaerophilus	Humans	Intestine
	Livestock	Intestine, Placenta, Fetus
Arcobacter skirrowii	Livestock	Intestine, Reproductive tract
Arcobacter nitrofigilis	*Spartina* plant	Roots

TABLE 5. Recovery of *Campylobacter* and *Arcobacter* from Feces of Healthy Dairy Cattle.

	Positive samples/Total	Percentage
Campylobacter jejuni	574/1,334	43.03%
Campylobacter coli	21/1,334	1.57%
Arcobacter spp	130/1,236	10.52%

children whose mothers did not practice premastication (Megraud, 1990). The higher prevalence of *H. pylori* infections in Chinese immigrants living in Melbourne, Australia was associated with age, birthplace, and the use of chopsticks, which may suggest oral-to-oral route of transmission (Chow et al., 1995).

Axon (1995) hypothesized that the natural route of infection may be by gastric juice as a result of vomiting low pH (achlorhydric) mucus in childhood. That ingestion of vomitus or saliva may facilitate transmission was suggested by studies involving experimental infection of puppies. *Helicobacter felis* and *Helicobacter heilmannii* ("Gastrospirillum hominis") can be transmitted from experimentally-infected dogs to native beagle puppies by contact with vomit, saliva, or gastric secretions. But cross-infection with these pathogens did not occur between mice, which, unlike dogs and cats, vomit infrequently and eat feces (Lee et al., 1991).

Close contact, poor sanitary conditions, familial crowding, sharing a bed during childhood, confinement in submarines, clustering in institutions, and contact with pets are risk factors for *H. pylori* infection (Goodman and Correa, 1995; Webb et al., 1994).

Fruits and Vegetables

The possible role of fruits and vegetables in *H. pylori* transmission is based on serosurveys and retrospective epidemiological studies. In a study of 1,815 Chileans under the age of 35, *H. pylori* antibodies were detected in >60% of lower socioeconomic groups (Hopkins et al., 1993). Seropositivity, or the presence of antibodies for *H. pylori*, correlated with age, low socioeconomic status, and consumption of uncooked vegetables. Risk factors that reached marginal significance included consumption of uncooked shellfish. Since contamination of irrigation water by raw sewage and subsequent contamination of raw vegetables is a prime factor in the transmission of enteric pathogens in Chile, *H. pylori* may be similarly transmitted.

A high intake of fruits and vegetables may actually protect against risk of gastritis caused by *Helicobacter* spp. (Hwang et al., 1994). Yet a comparison of vegetarians and meat-eaters indicated no significant difference in *H. pylori* seroprevalence between the two groups (Goodman and Correa, 1995, Webberley et al., 1992). Consumption of vitamin C and elevated plasma and gastric levels of vitamin C may eliminate infection (Goodman and Correa, 1995).

Other risk factors associated with clinical gastritis include poor nutritional status, consumption of salty, smoked or pickled foods, drinking caffeinated beverages, smoking, alcoholism, and immunosuppression associated with human immunodeficiency virus (HIV; (Goodman and Correa, 1995; Parsonnet et al., 1992).

To date, no isolations of *H. pylori* have been reported from vegetables, fruits, shellfish, or seafoods.

Water as a Vehicle of Transmission

Klein et al. (1991) concluded that in communities in the city of Lima, Peru, the water source may be a more important risk factor than socioeconomic status in acquiring *H. pylori* infection. The study involved 407 Peruvian children, (aged 2 months to 12 years), from families of low and high socioeconomic status. Infection was higher among children from low-income families (56%) than those from high-income families (32%, $p<0.001$). However, children from high income families whose homes were supplied with municipal drinking water were 12 times more likely to be infected than those from high-income families whose water supply came from community wells. Thus, the municipal water supply may represent an important source of infection regardless of socioeconomic status. In Colombia, swimming in rivers, drinking stream water, contact with sheep, eating raw vegetables, and the number of children in the household were correlated with increased risk of *H. pylori* infection (Goodman and Correa, 1995; Webb et al., 1994; Goodman et al., 1996).

Helicobacter pylori has been detected via PCR in sewage samples collected in a midwest American town and in water, including river water (Goodman and Correa, 1995; Webb et al., 1994). This suggests sewage-contaminated water as a source of transmission. However, chlorination studies completed in the United States by the Environmental Protection Agency indicate that *H. pylori* is as sensitive to standard chlorination regimens as *E. coli* (Johnson et al., 1993).

Meat Animals as Sources of Infection

Indirect evidence of transmission of *H. pylori* from meat animals to humans is derived from serosurveys or blood tests

TABLE 6. Recovery of *Campylobacter* and *Arcobacter* from Feces of Healthy Swine.

	Positive samples/Total	Percentage
Campylobacter jejuni	3/1,057	0.28%
Campylobacter coli	728/1,057	69%
Arcobacter spp	534/1,160	74%

TABLE 7. Comparison of the Recovery of *Arcobacter* spp. from Aborted Fetuses Versus Fetuses Obtained from the Slaughterhouse.

	Aborted	Slaughterhouse
Number of fetuses examined	400	214
Number positive	188	47
% positive fetuses[1]	47%	22%
Number of tissues examined	1,710	823
Number positive	418	50
% positive tissues[2]	24%	6%

[1] Differences between aborted fetuses and fetuses obtained from slaughterhouses are statistically significant (p<.001).
[2] Differences between tissues from aborted fetuses and fetuses obtained from slaughterhouse are statistically significant (p<.001).

of veterinarians and slaughterhouse workers. Antibodies to *H. pylori* were detected more frequently in slaughterhouse workers exposed to animal carcasses than in clerical workers employed at an Italian plant (Vaira et al., 1988). The highest titers occurred in female workers who slaughtered rabbits, which was the only meat animal species described in the study. However, no preemployment serological titers were included in the study to evaluate preexisting infection status. Likewise, comparisons between the clerical and nonclerical staff matched with respect to age, socioeconomic status, and country of origin were not provided.

In France, seropositivity for *H. pylori* was greater in slaughterhouse employees exposed to poultry (24%) and swine (14%) viscera than in age-matched controls who did not work at that abattoir (6%). Interestingly, antibody titers to *H. pylori* were lower in workers with more than 15 years of abattoir experience than in those with less experience (Husson et al., 1991). However, other studies have failed to confirm that seropositivity is associated with slaughterhouse work (Goodman and Correa, 1995).

Attempts to find *H. pylori* in livestock have been hampered in part due to the fastidious nature of the microbe and undoubtedly the difficulty of primary isolation. In swine, evidence of infection by *Helicobacter*-like organisms is indicated by serosurveys (Seidel et al., 1996), monoclonal antibody detection of *H. pylori*-like bacteria in stomachs (Vaira et al., 1992), and, in one survey, the presence of *Helicobacter*-like organisms in 53% of stomachs (Korber-Golze et al., 1993). However, these studies may warrant reexamination with more specific assays following the recognition of *H. heilmannii* ("Gastrospirillum suis") in all stomachs of pigs with ulcers and in 35% of normal stomachs (Queiroz et al., 1996). The phylogenetic proximity of *H. heilmannii* to *H. pylori* is strongly suggestive of antigenic cross-reactivity (Solnick et al., 1993).

Although *H. pamatensis* has been found in pigs (Dewhirst et al., 1994), in only a single study has *H. pylori* been isolated and verified by 16S rDNA sequencing in a pig (Ho et al., 1991). Again, the latter study was completed prior to the recent description of *H. heilmannii* in pigs (Queiroz et al., 1996). Taken together, the data suggest that pigs harbor their own species of *Helicobacter*, namely *H. heilmannii*, and may not be natural carriers of *H. pylori*. Thus, the risk of pork serving as a vehicle of transmission of *H. pylori* to humans is unlikely.

For cattle, a case-control study involving 30 unweaned beef calves with perforating or a hemorrhagic ulcer was conducted to determine the association of *H. pylori* with fatal abomasal ulcer formation. *Helicobacter*-like organisms, including *H. pylori*, were not visualized in or cultured from any of the abomasal tissue samples (Jelinski et al., 1995). The report of *H. pylori* antibodies in 6 of 22 (27%) of calf sera tested (Seidel et al., 1996) should be interpreted with caution and may be due to possible cross-reactivity with other bacterial antigens.

Although *H. pylori* was not detected in the intestinal tract of chickens (Boehmler et al., 1996), a new species, *H. pullorum*, was cultured from the caeca of healthy broilers, and the livers and intestinal contents of laying hens with hepatic lesions (Stanley et al., 1994). In a Swiss study of isolates from human gastroenteritis cases, 6 of 387 *Campylobacter* isolates (1.5%) were identified as *H. pullorum* (Burnens et al., 1994). This study indicates the possibility of transmission of *H. pullorum* from poultry to humans and its pathogenicity for the human host. Because *H. pullorum* resembles *Campylobacter coli* at the light microscope level, it could be overlooked as a cause of human enteritis (Burnens et al., 1994). However, the current availability of PCR primers for *Helicobacter* and *C. coli* will facilitate correct identification.

To summarize, although other *Helicobacter* species have been recovered in livestock, *H. pylori* has not been confirmed in cattle or poultry based on existing data, thus eliminating these meat animals as a source of infection. However, in developing countries, consumption of sewage-contaminated drinking water and vegetables may be a risk factor for *H. pylori* infection.

Arcobacter

The genus *Arcobacter* includes bacteria formerly designated *Campylobacter cryaerophila* (Latin; loving cold and air). *Arcobacter* (Latin; arc-shaped bacterium), unlike other *Campylobacter* species, grows in the presence of atmospheric oxygen (aerotolerant) and at 15°C (cryophilic), which is lower

TABLE 8. Recovery of *Arcobacter* spp. from Pigs at a Specific Pathogen-free (SPF) Farm and a Farm with Reproductive Problems.

	SPF farm		Problem farm	
Sows				
Vaginal swabs	4/21	19%	11/45	24%
Rectal swabs	3/21	14%	23/68	34%
Boars				
Preputial swabs	7/9	78%	14/17	83%
Rectal swabs	4/9	44%	Not tested	Not tested

than temperatures used for incubation of *Campylobacter* (Neill et al., 1985).

Arcobacter Infections in Humans and Animals

Three species of *Arcobacter* have been recovered from man and animals (Vandamme et al., 1993): *Arcobacter butzleri*, *Arcobacter cryaerophilus*, and *Arcobacter skirrowii* (Table 4). Of these *A. butzleri* is regarded as the primary human pathogen (Kiehlbauch et al., 1991).

Arcobacter infections in animals are associated with abortions and enteritis (see review by Wesley, 1994). Enteritis and occasionally septicemia occur in humans (Kiehlbauch et al., 1991). Primates naturally infected with *A. butzleri* develop colitis. This observation may provide insight into its pathogenesis in humans (Anderson et al., 1993).

For cattle, *Arcobacter* organisms have been detected from the feces of calves with diarrhea, animals with mastitis (see review by Wesley, 1994), and clinically healthy dairy cows. We detected *Arcobacter* in 10.52% of dairy cattle fecal samples (n=1,236, Table 5) by using PCR. In another study, *Arcobacter* spp. was cultured from only 1. 5% of minced beef (n=68) samples (deBoer et al., 1996).

Arcobacter is present in both healthy and clinically ill pigs (Schroeder-Tucker, 1996; Wesley , 1994). We detected *Arcobacter* spp. by PCR (Harmon and Wesley, 1996) in 40% of fecal samples obtained from clinically healthy swine (Table 6). In another study, we cultured significantly more ($p<0.001$) *Arcobacter* from aborted porcine fetuses than from fetuses obtained from a slaughterhouse (Table 7). Despite the association of *Arcobacter* with porcine abortions, no differences were seen in the recovery of *Arcobacter* spp. from rectal, preputial, or vaginal swabs taken from pigs from a herd with reproductive problems versus a herd of specific pathogen-free animals (Table 8). Experimental infections indicate that *Arcobacter* spp., especially *A. butzleri*, like *C. jejuni* and *H. pylori*, colonize neonatal piglets (Wesley et al., 1995).

Arcobacter in Foods

The association of *A. butzleri* with human enteritis, its recovery in hogs, and the susceptibility of neonatal piglets to infection suggests a possible association of *Arcobacter* spp. with pork products. Collins et al. detected *Arcobacter* in 89% of ground pork samples (n=149) obtained from an Iowa slaughter facility (Plant #1). In a later survey involving Plant #1 and four other premises (Plants #2 through #5), 90% of samples from Plant #1 were again positive (Collins et al., 1996). In contrast, only 5% of the total 120 samples from the four other facilities (Plants #2 through #5) yielded *Arcobacter* spp. It was not determined whether management practices at the source farms or the sanitary conditions during slaughter influenced the prevalence of *Arcobacter* spp. in ground pork. However, using an *Arcobacter* Selective Broth and Medium, deBoer et al. isolated the organism in only 0. 5% (1 of 194) of retail pork in the Netherlands. The difference between minimally-processed pork cuts and ground pork as well as isolation methods may explain the differences between the findings of the two studies.

Arcobacter, like *Campylobacter*, has been reported more frequently from poultry than from red meats. Thus, poultry may be a significant reservoir of *A. butzleri.* In France, *A. butzleri* was recovered from 81% of poultry carcasses examined (n=201). Nearly half of the poultry isolates in that study were of serogroup 1. Serogroups 1 and 5 are primarily associated with human infection (Lior and Woodward, 1993). In a survey of poultry products in Canada, *A. butzleri* was recovered from 97% (121 of 125) of poultry carcasses obtained from five different processing plants (Lammerding, 1997). In addition, *A. butzleri* was cultured from retail-purchased whole and ground poultry, chicken, and turkey samples. As was the case in the French study, serotype 1 was the predominant serotype isolated from Canadian poultry (Lammerding, 1997).

Arcobacter butzleri was detected in only 24% (53 of 224) of retail-purchased poultry in the Netherlands (deBoer, 1996). In contrast, Zenetti et al. (1996) in a limited study, failed to culture *A. butzleri* from poultry. We determined the prevalence of *Arcobacter* in mechanically-separated turkey samples. Of 200 samples obtained from a single processing plant in Iowa, *A. butzleri* was cultured from 76% of the samples (T. Manke et al., 1997). The differences in recovery rate could be attributed to multiple factors, including hygienic conditions at the farm or to variations in the sensitivity of isolation methods. It is interesting to note that despite repeated attempts, we have been unable to experimentally infect 3-day old chicks with *A. butzleri*.

The distribution of *Arcobacter* spp. in seafoods, shellfish, and raw milk is unknown. The presence of *A. butzleri* in poultry and meats, especially ground pork, prompted studies to determine its sensitivity to irradiation. By comparing values (the irradiation dose which reduces by 10-fold the number of viable bacteria), *A. butzleri* (0.27 kGy) was found to be more resistant to irradiation than *C. jejuni* (0.18 kGy). Thus, irradiation doses (1.5 to 4.5 kGy) approved by the U.S. Food and Drug Administration would eliminate *Campylobacter* as well as *Arcobacter* from ground pork (Collins et al., 1996).

Transmission in Water

Transmission of *A. butzleri* may involve drinking contaminated water (see review by Wesley, 1996). *Arcobacter* spp. may be more common in developing nations since *A. butzleri* accounted for 16% of the *Campylobacter*-like isolates made from cases of diarrhea in Thai children. A recent outbreak of gastroenteritis in a youth camp in Idaho was traced to *C. jejuni*. No attempt was made to culture for *Arcobacter* at that time. Water samples taken later from the incriminated well yielded *A. butzleri* (Rice, personal communication). The presence of *A. butzleri* in unchlorinated water supplies suggests this as a possible mechanism of contamination.

Species Identification by DNA-based Methods

The morphologic similarity between *Arcobacter* and *Campylobacter* may confound correct identificationæa problem addressed with the current availability of DNA probes (Wesley et al., 1995) and PCR primers (Bastyns et al., 1995, Harmon and Wesley 1996, 1997)

PCR assays to detect all members of the genus *Arcobacter* (Harmon and Wesley 1996, 1997) and which are specific for each of the species of *Arcobacter* have been reported (Bastyns et al., 1995). A multiplex PCR assay to simultaneously identify *Arcobacter* and *A. butzleri* in livestock and foods has been described (Harmon and Wesley, 1997).

DNA-based fingerprinting of field strains may provide insight into the source of *Arcobacter* contamination. PCR-mediated DNA fingerprinting confirmed the identity of *A. butzleri* isolates recovered from a nursery school outbreak and suggested person-to-person transmission (Vandamme et al., 1993). Based on the identical fingerprints, a single source of contamination and person-to-person transmission were suggested (Vandamme et al., 1993). PCR fingerprinting may also be used to identify *A. butzleri* isolates from meat. We have used DNA probes and PCR fingerprinting to analyze over 200 *A. butzleri* field strains recovered from mechanically separated turkey. The multiple DNA fingerprints indicated numerous sources of contamination (T. Manke et al., 1997).

Conclusions

We have briefly surveyed selected microbes of future concern and have focused on *H. pylori* and *Arcobacter* as potential human foodborne agents. *Helicobacter pylori* has been detected in water but not in meats or in livestock, with a single isolation made from a pig. In contrast, *Arcobacter* spp. have been found in livestock, meat, and in water. The thermotolerance of *Helicobacter* and *Arcobacter* may be similar to that of *C. jejuni*. However, no studies have been reported on the survival of *Arcobacter* following heating, refrigeration, or freezing. The survival of *Arcobacter* during standard chlorination procedures used for water treatment plants is unknown. Chlorination inactivates *Helicobacter* (Johnson et al., 1993) as does heating to 57°C for 4 min (Boehmler et al., 1996). Taken together, the data suggest the risk of transmission to humans of *H. pylori* and of *A. butzleri* via properly cooked foods and chlorinated water is negligible.

Acknowledgments

I thank Janice Eifling for surfing the internet to provide bibliographic assistance. I am grateful to Mrs. Kathy Ferris for her briefing on *Salmonella* DT 104. I acknowledge the secretarial help of Sandy Johnson.

References

—Multidrug-resistant *Salmonella* serotype *typhimurium*—Untied States, 1996. MMWR 46:308-310 (April 11, 1997).

Anderson, K.F., Kiehlbauch, J.A., Anderson, D.C., McClure, H.M. and Wachsmuth, I.K. 1993. *Arcobacter (Campylobacter) butzleri*-associated diarrheal illness in a nonhuman primate population. Infect. Immun. 61:2220-2223.

Axon, A.T.R. 1995. Is *Helicobacter pylori* transmitted by the gastro-oral route? Aliment. Pharmacol. & Ther. 9,585-588.

Banatvala, N. and Feldman, R. 1993. The Epidemiology of *Helicobacter pylori*: missing pieces in a jigsaw. Commun. Dis. Rep. CDR Rev. 3: R56-R59.

Bastyns, K., Cartuyvels, D., Chapelle, S., Vandamme, P., Goossens, H. and De Wachter, R. 1995. A variable 23S rDNA region is a useful discriminating target for genus-specific and species-specific PCR amplification in *Arcobacter* species. Syst. Appl. Microbiol: 18:353-356.

Besser, T.E., Gay, C.C., Gay, J.M., Hancock, D.D., Rice, D., Pritchett, L.C. and Erickson, E.D. 1997. Salmonellosis associated with *S. typhimurium* DT 104 in the USA. Vet. Rec. 140:75.

Blaser, M.J. 1993. *Helicobacter pylori*: Microbiology of a 'slow' bacterial infection. Trends Microbiol. 1:255-260.

Boehmler, G., Gerwert, J., Scupin, E. and Sinell, H.J. 1996. Epidemiology of *H. pylori* in man: studies on the survival of the agent in food. Deutsche Tieraerztliche Wochenschrift 103:438-443.

Burnens, A.P., Stanley, J., Morgenstern, R., and Nicolet, J. 1994. Gastroenteritis associated with *Helicobacter pullorum*. Lancet 344:1569-1570.

Chow, T.K.F., Lambert, J.R., Wahlqvist, M.L. and Hsuhage, B.H.H. 1995. *H. pylori* in Melbourne Chinese immigrants: evidence for oral-oral transmission via chopsticks. J. Gastroenterol. Hepatol. 10:561-569.

Collins, C.I., Wesley, I.V., and Murano, E.A. 1996. Detection of *Arcobacter* spp. in ground pork by modified plating methods. J. Food Prot. 59:448-452.

Collins, C.I., Murano, E.A., and Wesley, I.V. 1996. Survival of *Arcobacter butzleri* and *Campylobacter jejuni* after irradiation treatment in vacuum packaged ground pork. J. Food Prot. 11:1164-1166.

de Boer, E., Tilburg, J.J.H.C., Woodward, D.L., Lior, H.L., and Johnson, W.M. 1996. A selective medium for the isolation of *Arcobacter* from meats. Lett. Appl. Microbiol. 23:65-66.

Davies, A., O'Neill, P., Towers, L., and Cooke, M. 1996. An outbreak of *Salmonella typhimurium* DT 104 food poisoning associated with eating beef. Commun. Dis. Rep. 6:R159-R162.

Dewhirst, F.E., Seymour, C., Fraser, G.J., Paster, B.J., and Fox, J.G. 1994. Phylogeny of *Helicobacter* isolates from bird and swine feces and description of *Helicobacter pametensis sp.* nov. Int. J. Syst. Bacteriol. 44:553-560.

Evans, S., and Davies, R. 1996. Case control study of multiple resistant *Salmonella typhimurium* DT 104 infection of cattle in Great Britain. Vet. Rec. 139:557-558.

Fone, D.L., and Barker, R.M. 1994. Association between human and farm animal infections with *Salmonella typhimurium* DT 104 in Herefordshire. Commun. Dis. Rep. 4:R136-R140.

Gibson, G.R., Kelly, S.M., Macfarlane, S., and Macfarlane, G.T. 1995. Methodology for the isolation of *Helicobacter pylori* from faeces of persons in the United Kingdom. J. Microbiol. Methods. 23:321-328.

Goodman, K.H.J., and Correa, P. 1995. The Transmission of *Helicobacter pylori*: A critical review of the evidence. Int. J. Epidemiol. 224:875-887.

Goodman, K.H.J., Correa, P., Aux, H.J.T., Ramirez, H., DeLany, J.P., Pepinosa, O.G., Quinones, M.L., and Parra, T.C. 1996. *Helicobacter pylori* infection in the Colombian Andes: A population based study of transmission pathways. Am. J. Epidemiol. 144:290-299.

Goodwin, C.S., and Worsley, B.W. 1993. *Helicobacter pylori*: Biology and Clinical Practice. CRC Press. Boca Raton, Florida.

Harmon, K.M., and Wesley, I.V. 1996. Identification of *Arcobacter* isolates by PCR. Lett. Appl. Microbiol. 23:241-244.

Harmon, K.M., and Wesley, I.V. 1997. Multiplex PCR for the identification of *Arcobacter* differentiation of Arcobacter butzleri from other arcobacters. Vet. Micro. (accepted)

Ho, S.A., Hoyle, J.A., Lewis, F.A., Secker, A.D., Cross, D., Mapstone, N.P. et al. 1991. Direct Polymerase chain reaction test for detection of *Helicobacter pylori* in humans and Animals. J. Clin. Microbiol. 29:2543-2549.

Hopkins, R.J., Ferreccio, C., Ovalle, J., Prado, P., and Sotomayor, V. 1993. Seroprevalence of *Helicobacter pylori* in Chile: Vegetables may serve as one route of transmission. J. Infect. Dis. 168:222-226.

Husson, M., Vincent, P., Grabiaud, M., Furon, D., and Leclerc, H. 1991. Anti- *Helicobacter pylori* IgG levels in abattoir workers. Gastroenterol. Clin. Biol. 15:723-726.

Hwang, H., Dwyer, J., and Russel, R.M. 1994. *Helicobacter pylori* infection, food preservation and gastric cancer risk: Are there new roles for preventative factors? Nutr. Rev. 52:75-83.

Jelinski, M., Ribble, C.S., Chirino-Trejo, M., Clar, E.G., and Janzen, E.D. 1995. The relationship between the presence of *Helicobacter pylori*, *Clostridium perfringens* type A, *Campylobacter* spp. or fungi and fatal abomasal ulcers in unweaned beef calves. Can. Vet. J. 36, 379-382.

Johnson, C.H., Rice, E.W., and Reasoner, D.H.J. 1993. Inactivation of *Helicobacter pylori* by free chlorine, abstr. Q265, p. 394. 93rd Annu. Meet. Am. Soc. Microbiol.

Johnson, R.G., Clarke, R.C., Wilson, J.B., Read, S.C., Rahn, K., Renwick, S.A., Sandhu, K.A., Alves, D., Karmali, M.A., Lior, H., McEwen, S.A., Spika, J.S., and Gyles, C.L. 1996. Growing concerns and recent outbreaks involving non–O157:H7 serotypes of verotoxigenic *Escherichia coli*. J. Food Prot. 59:1112-1122.

Kiehlbauch, J.A., Brenner, D.J., Nicholson, M.A., Baker, C.N., Patton, C.M., Steigerwalt, A.G., and Wachsmuth, I.K. 1991. *Campylobacter butzleri* sp. nov. isolated from humans and animals with diarrheal illness. J. Clin. Microbiol. 29,376-385.

Klein, P.D., Graham, D.Y., Gaillour, A., Opekun, A.R., and O'Brian Smith, E. 1991. Water source as risk factor for *Helicobacter pylori* infection in Peruvian children. Lancet 337:1503-1506.

Korber-Golze, B., and Scupin, E. 1993. *Helicobacter pylor*-investigations of pigs. Dtsch. Tieraerztl. Wochenschr. 100:465-468.

Lammerding, A. 1997. Isolation method for recovery of *Arcobacter butzleri* from fresh poultry and poultry products. Campylobacter VIII (Newall, D.G. and Ketley, H.J., eds.), Plenum Publ. Corp. (in press)

Lee, A. 1991. Transmission of *Helicobacter* spp.: A challenge to the dogma of faecal-oral spread. Epidemiol. Infect.: 107, 99-109.

Lior, H.J., and Woodward, D.L. 1993. *Arcobacter butzleri*: A serotyping scheme. Acta. Gastro. Enterologica Belgica 56: (Suppl):29.

Manke, T.R., Wesley, I.V., Harmon, K., and Dickson, J. 1997. Prevalence and genetic variability of *Arcobacter* and *Arcobacter butzleri* in mechanically separated turkey. J. Food Protection (submitted).

Megraud, F. 1990. Epidemiological study of *Helicobacter pylori* transmission from mother to child in Africa. Rev. Esp. Enferm. Dig. 78 (suppl. 1), 48.

Moon, H.W. 1996. Bovine spongiform encephalopathy: Hypothetical risk of emergence of as Ázoonotic foodborne epidemic. J. Food Prot. 59:1106-1111.

Neill, S.D., Campbell, J.N., O'Brien, J.J., Weatherup, S.T.C., and Ellis, W.A. 1985. Taxonomic position of *Campylobacter cryaerophila* sp. nov. Int. J. Syst. Bacteriol. 342-356.

Nettles, V.F. 1996. Reemerging and emerging infectious diseases: Economic and other impacts on wildlife. ASM. Public and Scientific Affairs Board, pp. 10-13.

Nguyen, A.H., El-Zaatari, A., and Graham, D.Y. 1995. *Helicobacter pylori* in the oral cavity: A critical review of the literature. Oral Surg. Oral Med. Oral Pathol. 76:705-709.

Parsonnet, J., Blaser, M.H., Perez-Perez, G.I., Hargrett-Bean, N. and Tauxe, R.V. 1992. Symptoms and risk factors of *Helicobacter pylori* infection in a cohort of epidemiologists. Gastroenterology 102:41-46.

Queiroz, D.M.D., Rocha, G.A., Mendes, E.N., deMoura, S.B., deOliveira, A.M.R., and Miranda, D. 1996. Association between *Helicobacter* and gastric ulcer disease of the pars esophagea in swine. Gastroenterology 111:19-27.

Rees, J.H., Soudain, S.E., Gregson, N.A., and Hughes, R.A. 1995. *Campylobacter jejuni* infection and Guillain-Barre syndrome. N. Eng. J. Med. 333:1374-1379.

Schroeder-Tucker, L., Wesley, I.V., Kiehlbauch, J., Larson, D.J., Thomas, L., and Erickson, G.A. 1996. Phenotypic and ribosomal RNA characterization of *Arcobacter* species isolated form porcine aborted fetuses. J. Vet. Diagn. Invest. 8, 186-195.

Seidel, K.E., Kampschulte, J., Lehn, and Bauer, J. 1996. *Helicobacter pylori*: Antikorper in seren von schweinen und kalbern. Berl. Muench. Tieraeztl. Wochenschr. 109:434-439.

Shadduck, J.A., Storts, R., and Adams, L.G. 1996. Selected examples of emerging and reemerging infectious diseases in animals. ASM. Public and Scientific Affairs Board pp. 6-9.

Solnick, J.V., O'Rourke, J., Lee, A., Paster, B.J., Dewhirst, F.E., and Tompkins, L.S. 1993. An uncultured gastric spiral organism is a newly identified *Helicobacter* in humans. J. Infect. Dis. 168, 379-385.

Stanley, J., Linton, D., Burnens, A.P., Dewhirst, G.F.E., On, S.L.W., Porter, A., Owen, R.J., and Costas, M. 1994. *Helicobacter pullorum* sp. nov.-genotype and phenotype of a new species isolated from poultry and from human patients with gastroenteritis. Microbiology 140:3441-3449.

Talley, N.J., and Noack, K.B. 1993. The worldwide prevalence of *Helicobacter pylori*: asymptomatic infection and clinical states associated with infection in adults. In *Helicobacter pylori*: Biology and Clinical Practice (Goodwin, C.S. and Worsley, B.W., eds.), pp. 63-84, CRC Press.

Takeda, Y. 1997. The 1996 outbreak of enterohemorrhagic *Escherichia coli* infection in Japan. International Life Sciences Institute Conference on Emerging Foodborne Pathogens. Abst. p. 26.

Threllfall, E.J., Frost, J.A., Ward, L.R., and Rose, B. 1996. Increasing spectrum of resistance in multiresistant *Salmonella typhimurium*. Lancet 347:1053-1054.

Vaira, D. et al. (1988). *Campylobacter pylori* in abattoir workers: Is it a zoonosis. Lancet 2:725-726.

Vaira, D., Ferron, P., Negrini, R., Cavazzini, L., Holton, H.J. et al. 1992. Detection of *Helicobacter pylori*-like organisms in the stomach of some food-source animals using a monoclonal antibody. Ital. J. Gastroenterol. 24, 181-184.

Vandamme, P., Vancanneyt, M., Pot, B., Mels, L., Hoste, B., Dewettinck, D., Vlaes, L., Van Den, Borre C., Higgins, R., Hommez, J., Kersters, K., Butzler, J.-P., and Goossens, A. 1992. Polyphasic taxonomic study of the emended genus *Arcobacter* with *Arcobacter butzleri* comb. nov. and *Arcobacter skirrowii* sp. nov., an aerotolerant bacterium isolated from veterinary specimens. Int. J. Syst. Bacteriol. 42, 344-356.

Vandamme, P., Falsen, E., Rossau, R., Hoste, B., Segers, P., Tytgat, R., and De Ley, J. 1991. Revision of *Campylobacter, Helicobacter,* and *Wolinella* taxonomy: emendation of generic descriptions and proposal of *Arcobacter* gen. nov. Int. J. Syst. Bacteriol. 41:88-103.

Vandamme, P., Giesendorf, A.J., VanBelkum, A., Pieraard, D., Lauwers, S., Kersters, K., Butzler, J.-P., Goossens, H., and Quint, W.G.V. 1993. Discrimination of epidemic and sporadic isolates of *Arcobacter butzleri* by polymerase chain reaction-mediated DNA fingerprinting. J. Clin. Microbiol. 31,3317-3319.

Vidaver, A.K.L. 1996. Emerging and reemerging infectious diseases: Perspectives on plants, animals and humans. ASM Public and Scientific Affairs Board, pp. 3-5.

Wall, P.G., Morgan, D., Lamden, K., Ryan, M., Griffin, M., Threlfal, E.J., and Ward, L.R. Rowe. 1994. A case control study of infection with an epidemic strain of multiresistant *Salmonella typhimurium* DT 1204 in England and Wales. Commun. Dis. Rep. 4:R130-R135.

Webb, P.M. et al. 1994. Relation between infection with *Helicobacter pylori* and living conditions in childhood: Evidence for person to person transmission in early life. Br. Med. J. 308,750-753.

Webberley, M.J., Webberley, J.M., Newell, D.G., Lowe, P., and Melikian, V. 1992. Seroepidemiology of *Helicobacter pylori* infection in vegans and meat-eaters. Epidemiol. Infect. 108:457-462.

Wesley, I.V., Schroeder-Tucker, L., Baetz, A., Dewhirst, F.E., and Paster, B.J. 1995. Oligonucleotide probes for the genus *Arcobacter* and for *Arcobacter butzleri* based on 16S rRNA sequence. J. Clin. Microbiol. 77:1691-1698.

Wesley, I.V. 1994. *Arcobacter* Infections. In: Handbook of Zoonoses (Beran, G.W. and Steele, J.H., eds.), pp.181-190, CRC Press 41.

Wesley, I.V. 1996. *Helicobacter* and *Arcobacter* species: risks for foods and beverages. J. Food Prot. 59, 1127-1132.

Wesley, I.V., Baetz, A.L., and Larson, D.J. 1995. Infection of Cesarean-derived colostrum-deprived I-day-old piglets with *Arcobacter butzleri*, *Arcobacter cryaerophilus*, and *Arcobacter skirrowii*. Infect. Immun. 64, 2295-2299.

Yeomans, N.D., and Kolt, S.D. 1996. *Helicobacter heilmannii* (formerly Gastrospirillum): association with pig and human gastric pathology. Gastroenterology 111:244-247.

Zanetti, F., Varoli, O., Stampi, S., and de Luca, G. 1996. Prevalence of thermophilic *Campylobacter* and *Arcobacter butzleri* in food of animal origin. Intl. J. of Food Microbiol. 33:315-321.