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Food Control 12 (2001) 1–6

FOOD CONTROL

www.elsevier.com/locate/foodcont

Review

Arcobacters as emerging human foodborne pathogens

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Received 15 April 2000; received in revised form 1 June 2000; accepted 5 June 2000

Abstract

Arcobacter spp. are increasingly being isolated from a wide range of foods especially those of animal origin, such as pork and poultry, and products derived from these. Although its role in the disease process remains to be fully elucidated, there have been several reports of the organism being implicated in human illness. This article reviews the procedures that have been developed for the isolation and identification of *Arcobacter* spp. which have lead to its detection in a wide range of animals and foods and discusses the role that this organism may have in the epidemiology of foodborne disease. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: *Arcobacter* spp.; Food; Human infections

Contents

1. Introduction

Vandamme et al. (1991) proposed the genus *Arcobacter* within the RNA Superfamily VI to describe those organisms previously classified as 'aerotolerant campylobacters'. The genus *Arcobacter* is included in the family *Campylobacteraceae* (Vandamme & De Ley, 1991a). There are four defined species: *Arcobacter butzleri*, *Arcobacter cryaerophilus* (Groups 1A and 1B), *Arcobacter skirrowii* and *Arcobacter nitrofigilis* (Vandamme et al., 1992a), of which the first three have been associated with human illness. Arcobacters are gram-negative, non-sporing, curved rods which may appear as spiral. Unlike thermophilic, pathogenic campylobacters, they grow at 15°C but not at 42°C and are able to grow aerobically at 30°C. Minimum standards for describing new species within this family have been determined (Ursing, Lior, & Owen, 1994).

2. Isolation and identification

A number of isolation methods have been suggested for *Arcobacter* spp., some of which have been derived

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PII: S0956-7135(00)00024-4

from those developed for campylobacters. CAT (cefoperazone, amphotericin, teicoplanin) agar supports growth of a wider range of arcobacters than mCCDA (modified cefoperazone, charcoal, deoxycholate agar) (Corry & Atabay, 1997). A pre-enrichment stage in either CAT broth or Arcobacter Enrichment Broth together with a filter method (Lammerding, Harris, Lior, Woodward, Cole, & Muckle, 1996) onto mCCDA or CAT agar has been suggested for optimum isolation from chicken carcasses (Atabay & Corry, 1997). A pre-enrichment in a Arcobacter Selective Broth (ASB), followed by plating onto semisolid Arcobacter selective medium using cefoperazone, trimethoprim and cycloheximide, has been suggested for isolation from raw poultry meats. The incorporation of piperacillin into the medium prevents the outgrowth of *Pseudomonas* spp. from raw meats at the isolation temperature of 24°C and results in isolation of *Arcobacter* spp. from 53 out of 220 poultry meat samples (De Boer, Tillburg, Woodward, Lior, & Johnson, 1996). A new commercial enrichment broth Arcobacter Broth has been developed in the UK which may be used supplemented with CAT or mCCD for isolation of *Arcobacter* spp. or *A. butzleri*, respectively. This medium supports good growth of *A. butzleri*, *A. cryaerophilus*, and *A. skirrowii* although *A. nitrofigilis* grows poorly. The growth characteristics in Arcobacter Broth compare favourably with those on media specifically designed for isolation of campylobacters (Atabay & Corry, 1998). Use of this medium allows high population densities to be achieved and eliminates the necessity for biphasic growth methods (Dickson, Manke, Wesley, & Baetz, 1996) which may be technically more difficult.

Although aerotolerance is a definitive characteristic which distinguishes *Arcobacter* spp. from *Campylobacter* spp., this is often not observed on initial isolation on media originally designed for the isolation of campylobacters (de Boer et al., 1996). Recently a new solid medium has been suggested for optimal aerobic growth at 30°C. The addition of 0.05% thioglycolic acid, 0.05% sodium pyruvate and 5% sheep's blood (pH 6.9) to a basal nutrient mix results in an effective medium for growth, with the added characteristic that a deep red colour develops around the colonies (Johnson & Murano, 1999a). An aerobic pre-enrichment with the so-called JM enrichment broth together with plating on this agar resulted in *Arcobacter* spp. being detected in 42 out of 50 broiler chicken samples compared with 15 with the de Boer et al. (1996) method (Johnson & Murano, 1999b).

The use of a systematic range of biochemical tests, together with a probabilistic matrix comparing the characteristics of the unknown isolate with those of defined taxa, provides a method of identification of different species. However, these are only helpful if there is a match between the taxa in the scheme and the unknown isolate. The original described scheme (Barrett, Patton, & Morris, 1988) and the commercially available scheme (API Campy, Biomérieux SA, France) only include 16 and 18 taxa, respectively. The latter, although effective for differentiation of *Campylobacter* spp., does not allow similar identification of *Arcobacter* at species level. *A. cryaerophilus* is the only one in the scheme and, even so, because of strain variability, it cannot be used for reliable identification (Jacob, Lior, & Feuerpfeil, 1993). SDS-PAGE of whole cell proteins has been shown to be successful in species level identification of *Arcobacter* spp. isolated from poultry at the abattoir (Ridsdale, Atabay, & Corry, 1998). Numerical analysis of phenotypic characters and use of an extensive probabilistic identification matrix confirms the differences between the three pathogenic *Arcobacter* spp. as a distinct group and *Campylobacter* spp. However, although *A. nitrofigilis* clusters with *C. curvis*, *C. rectus* and *C. showae* in another group, the former can be distinguished by aerobic growth at 25°C, making this characteristic an useful species-specific marker (On & Holmes, 1995; On, Holmes, & Sackin, 1996).

Identification of species within the family *Campylobacteriacae* using standard biochemical tests is problematical because of the variability and atypical reactions of some strains resulting in mis-classification and possibly mis-identification, in epidemiological studies, of common sources of infection. In the latter case identification at species level is required making molecular typing techniques the method of choice. Species of *Arcobacter* are reliably identified using restriction length polymorphism or ribotyping involving the hybridization of *Pvu*II-digested chromosomal DNA with probes for the 16S rRNA gene (Kiehlbauch, Plikaytis, Swaminathan, Cameron, & Wachsmuth, 1991; Wesley, Schroeder-Tucker, Baetz, Dewhirst, & Paster, 1995). Using primers targeted at these genes a PCR assay has been developed which has proved robust. The method may not only be used with purified DNA but also with crude cell lysate, thus reducing the time of identification to about 8 h compared with several days using conventional culturing techniques (Harmon & Wesley, 1996). A molecular identification scheme based on restriction profiles targeting the 23S rRNA gene, using three restriction endonucleases *Hpa*II, *Cfo*I and *Hinf*I allows differentiation of *A. butzleri* and *A. nitrofigilis* but not between *A. cryaerophilus* and *A. skirrowii* which have identical patterns with all restriction enzymes. The 23S rRNA gene-based PCR-RFLP identification generates conserved restriction profiles and because the 23S rRNA gene contains more recognition sites its use improves discrimination and specificity (Hurtado & Owen, 1997). Although PCR is a resource-laden method for routine isolation, in epidemiological studies use of a robust PCR will allow the source(s) and spread of the contamination to be identified.

3. Reservoirs in the environment

The first description of *Arcobacter* spp. (then referred to as aerotolerant *Campylobacter* spp.) was from isolates from aborted and normal porcine foetuses (Ellis, Neill, O'Brien, Ferguson, & Hanna, 1977), sows with reproductive problems and asymptomatic pigs (Neill, Ellis, & O'Brien, 1978, 1979).

In Brazil *A. cryaerophilus* has been isolated from sows with reproductive problems and from aborted porcine foetuses (De Oliveria, Baetz, Wesley, & Harmon, 1997) with 1B being found most commonly. However, in male pigs *A. cryaerophilus* 1A and 1B seem to be evenly distributed and are more common than *A. butzleri* (De Oliveria, Wesley, Baetz, Harmon, Kader, & de Uzeda, 1999). In one study gastric ulceration of swine was associated with *Arcobacter* spp., particularly *A. butzleri,* infection. The identification of the species involved seems to be dependent on the specificity of the PCR reaction used (Suarez, Wesley, & Larson, 1997).

Pork is routinely contaminated by *Arcobacter* spp., particularly *A. butzleri*, with varying prevalences at the processing plant. In one study of five such plants in Iowa, the inter-plant variation was between 90% and 0%. The variation between different plants depends on either the original primary source of the animals, or the hygiene practices at the abattoir itself, or both (Collins, Wesley, & Murano, 1996a).

Arcobacter spp. has been isolated from poultry with recovery rates ranging from 0% to 97% and although chickens are a source, eggs do not seem to be infected. In one study in Italy no *A. butzleri* was isolated from samples of either manually shelled eggs or retail chicken (Zanetti, Varoli, Stampi, & De Luca, 1996) whereas in another in The Netherlands 24.1% of 220 poultry meat products were positive for *Arcobacter.* In Canada, *A. butzleri* was recovered from 97% of poultry carcasses from five different processing plants (Lammerding et al., 1996). *A. butzleri* is not the only *Arcobacter* spp. present in poultry. *A. skirrowii* and *A. cryaerophilus* have also been isolated from chickens at the abattoir as well as on retail sale (Atabay, Corry, & On, 1998).

As well as chickens other poultry have been reported as harbouring the organism. A survey of mechanically separated turkey samples has suggested that this meat may be highly contaminated by *Arcobacter* spp. (77%) or *A. butzleri* (56%). As in the case of pig processing plants there was variation in prevalence. One plant yielded 96% of samples contaminated with *Arcobacter* species (80% of which were *A. butzleri*) whereas *Arcobacter* spp. was isolated from 44% of samples from another, 59% of these positive for *A. butzleri*. Using PCR-based fingerprinting to identify the organisms there was a diversity in DNA patterns within all plants sampled suggesting that there probably is a multiplicity of contaminating sources rather than one major source (Manke, Wesley, Dickson, & Harmon, 1998). In a study of ten duck carcasses at the abattoir *A. butzleri* was isolated from two, *A. skirrowii* from one and *A. cryaerophilus* from five. Out of four flocks investigated one was positive for *A. butzleri* and one for *A. cryaerophilus* (Ridsdale et al., 1998).

Despite its common isolation from poultry carcasses, *A. butzleri* is infrequently isolated from caecal samples suggesting that contamination may be post-slaughter (Atabay & Corry, 1997; Harrass, Schwarz, & Wenzel, 1998). However, natural infections of live poultry do occur. In one study, *Arcobacter* spp. was isolated from 14.3% of cloacal swabs from 405 birds of which 1% were *A. butzleri*. As with pigs, variations in isolation rate from poultry occur which seems to be dependent on the environmental conditions of the originating flock. However, unlike piglets, *per os* experimental infections with *A. butzleri* are not readily established in poultry. Only in the highly inbred Beltsville White turkeys was *A. butzleri* recovered from cloacal swabs or tissues of a majority of the experimentally infected birds (Wesley & Baetz, 1999).

Water probably has a significant role in the transmission of *Arcobacter* spp. both to animals and to humans. *A. butzleri* has been isolated from canal water in Thailand (Dhamabutra, Kamol-Rathanakul, & Pienthaweechai, 1992). In a two year study of water treatment plants in Germany the organism was isolated from all stages of the processing, although more frequently from raw compared with treated water. Serotype 1 was the predominant type isolated followed by serotypes 17, 19 and 2 (Jacob, Woodward, Feuerpfeil, & Johnson, 1998). This corresponds to other studies in poultry (Lammerding et al., 1996; Marinescu, Collignon, Squinazi, Woodward, & Lior, 1996a) and clinical samples (Vandamme, Pugina, Benzi, van Etterijk, Vlaes, Kersters, Butlzer, Lior, & Lauwers, 1992b) which have showed similar prevalences of serotypes. *A. butzleri* has been isolated from a well-water source in USA. However, the organism seems sensitive to chlorine inactivation so that infection probably occurs because of improper chlorination procedures or post-treatment contamination (Rice, Rodgers, Wesley, Johnson, & Tanner, 1999). *A. butzleri* has been found in various types of sewage sludge from treatment plants in Italy. Frequencies varied from 41% in digested sludges (values of 7649 MPN/g) to 80% in thickened and activated sludges. In comparison *C. jejuni* and *C. coli* were only isolated from primary sludge and at counts of 278 and 1403 MPN/g, respectively suggesting that land application of anaerobically digested sludge may cause high risk of infection (Stampi, Deluca, Varoli, & Zanetti, 1999).

4. Arcobacter and human infections

The organism has been associated with animal diseases including abortion, mastitis and diarrhoea

(Wesley, 1996). *A. butzleri* infection occurs in non-human primate populations (Anderson, Kiehlbauch, Anderson, McClure, & Wachsmuth, 1993) although there is no evidence at present to suggest that handling of such animals provides a means of human infections. In the case of a chronic diarrhoeic macaque (*Macaca mulatta*) no human infections were reported in people associated with the animal even though it was showing symptoms for ten months (Higgins, Messier, Daignault, & Lorange, 1999).

A. butzleri has been isolated from patients with severe diarrhoea (Lerner, Brumberger, & Preac-Mursic, 1994; Marinescu, Collignon, Squinazi, Derimay, Woodward, & Lior, 1996b) and from blood, including a case of neonatal bacteraemia (On, Stacey, & Smyth, 1995). The first description of a clinical case of *A. cryaerophilus* 1B human infection was in a homosexual male with diarrhoea (Tee, Baird, Dyall-Smith, & Dwyer, 1988). Clinical isolates have been reported in children with diarrhoea (Taylor, Kiehlbauch, Tee, Pitarangsi, & Echeverria, 1991) although the definitive association between human illness and pathogenicity of this organism remains uncertain. A case of an uremic patient with bacteriaemia caused by *A. cryaerophilus* 1B suggests that this organism is able to cause invasive infections (Hsueh, Teng, Yang, Wang, Chang, Ho, Hsieh, & Luh, 1997) although the patient concerned had an underlying illness which may have contributed to the progress of *A. cryaerophilus* infection.

The importance of *Arcobacter* spp. in the causation of human illness remains to be determined. This is probably because optimal isolation techniques have not yet been established and routine primary screening procedures used for *Campylobacter* spp. do not allow recovery of *Arcobacter* spp., which do not grow at 42°C (Marinescu et al., 1996b). The symptoms of *Arcobacter* infection are similar to campylobacteriosis and may be transient in nature making infection rates difficult to assess.

A study in Belgium carried out between 1991 and 1994 which screened all routine stool specimens submitted for detection of enteropathogens found that less than 0.1% were positive for *Arcobacter* (8 out of 21 527 samples). However, the method included non-selective isolation medium and microaerophilic conditions, which may not be the optimum conditions for isolation of the organism. Using the same isolation procedure no *Arcobacter* isolates were obtained from 879 samples from 468 elderly patients during a one year study (Lauwers, Breynaert, Van Etterijck, Revets, & Mets, 1996).

A porcine model has proved valuable in evaluating the pathogenicity of both *Campylobacter* spp. (Babakhani, Bradley, & Joens, 1993) and *Helicobacter* spp. (Eaton, Brooks, Morgan, & Krakowka, 1991; Eaton, Morgan, & Krakowka, 1992). *Arcobacter* spp. are able to colonise neonatal piglets as indicated by faecal shedding and re-isolation from tissues such as liver, kidney, ileum and brain although no gross pathology is observed. *A. butzleri* is particularly able to colonise piglets and use of this model for investigating the pathogenesis of this organism in humans may prove to be useful (Wesley, Baetz, & Larson, 1996).

An in vitro study suggests that *A. butzleri* produces cytotoxic effects on Hela cells and Intestine 407 cells and that the strains that do not, produce a cytotonic effect instead. This effect on cells in vitro probably reflects the potential virulence of this organism in vivo (Musmanno, Russi, Lior, & Figura, 1997).

5. Control

Although *Arcobacter* and *Campylobacter* are closely related this does not necessarily mean that treatments designed to eliminate the latter from various foods, particularly those of animal origin, are as effective inactivating or removing *A. butzleri*. For example, *A. butzleri* is more resistant than *C. jejuni* to irradiation treatment. The average D_{10} value is 0.27 kGy compared with 0.19 kGy for *C. jejuni*. Doses of irradiation currently allowed for pork in USA (0.3–1.0 kGy) provides an effective method of reducing, if not completely eliminating, *A. butzleri* from pork (Collins, Murano, & Wesley, 1996b). Treatment with sprays of organic acids has been shown to be effective at reducing *Salmonella* and *Campylobacter* spp. on pork carcasses (Epling, Carpenter, & Blankenship, 1993) and incorporating nisin and/or sodium lactate into fresh pork sausage has been suggested in order to reduce bacterial contamination especially *Staph. aureus* and *Salmonella kentucky* (Scannell, Hill, Buckley, & Arendt, 1997). Sodium lactate is not effective in reducing growth of *A. butzleri* in pure cultures (Phillips, 1999) but this does not mean that it is not effective in the complex ecosystems represented by food systems.

Implementation of hazard analysis and critical control points (HACCP) programs is important in the control of all foodborne pathogens, including *A. butzleri* and other species. However, changes in food processing, food handling practices and the development of novel food products, together with consumer influences will ensure that emerging foodborne pathogens will continue to be an important public health concern (Meng & Doyle, 1997).

6. Conclusion

The role of *Arcobacter* spp. is not, as yet, defined in terms of human foodborne illness. However, as more sophisticated detection, isolation and identification techniques are developed more information will be

gathered on its epidemiology and sources both in the environment and in food. Thus, although presently *A. butzleri* itself, or *Arcobacter* spp. in general, do not appear to play a major role in human foodborne disease, it may certainly be added to the ranks of the potential 'emerging foodborne pathogens.'

References

Anderson, K. F., Kiehlbauch, J. A., Anderson, D. C., McClure, H. M., & Wachsmuth, I. K. (1993). *Arcobacter* (*Campylobacter*) *butzleri*-associated diarrhoeal illness in a non-human primate. *Infection and Immunity*, *61*, 2220–2223.

Atabay, H. I., & Corry, J. E. L. (1997). The prevalence of campylobacters and arcobacters in broiler chickens. *Journal of Applied Microbiology*, *83*, 619–626.

Atabay, H. I., & Corry, J. E. L. (1998). Evaluation of a new arcobacter enrichment medium and comparison with two media developed for enrichment of *Campylobacter* spp. *International Journal of Food Microbiology*, *41*, 53–58.

Atabay, H. I., Corry, J. E. L., & On, S. L. W. (1998). Diversity and prevalence of *Arcobacter* spp. in broiler chickens. *Journal of Applied Microbiology*, *84*, 1007–1016.

Babakhani, F. K., Bradley, G. A., & Joens, L. A. (1993). Newborn piglet model for campylobacteriosis. *Infection and Immunity*, *61*, 3466–3475.

Barrett, T. C., Patton, C. M., & Morris, G. K. (1988). Differentiation of *Campylobacter* species using phenotypic characterisation. *Laboratory Medicine*, *19*, 94–102.

Collins, C. I., Wesley, I. V., & Murano, E. A. (1996a). Detection of *Arcobacter* spp. in ground pork by modified plating methods. *Journal of Food Protection*, *59*, 448–452.

Collins, C. I., Murano, E. A., & Wesley, I. V. (1996b). Survival of *Arcobacter butzleri* and *Campylobacter jejuni* after irradiation treatment in vacuum-packaged pork. *Journal of Food Protection*, *59*, 1164–1166.

Corry, J. E. L., & Atabay, H. I. (1997). Comparison of the productivity of cefoperazone, amphotericin, teicoplanin (CAT) agar and modified cefoperazone, charcoal, deoxycholate (mCCD) agar for various strains of *Campylobacter*, *Arcobacter* and *Helicobacter pullorum*. *International Journal of Food Microbiology*, *38*, 201–209.

De Boer, E., Tillburg, J. J. H. C., Woodward, D. L., Lior, H., & Johnson, W. M. (1996). A selective medium for the isolation of arcobacter from meats. *Letters in Applied Microbiology*, *23*, 64–66.

De Oliveria, S. J., Baetz, A. L., Wesley, I. V., & Harmon, K. M. (1997). Classification of *Arcobacter* species isolated from aborted pig fetuses and sows with reproductive problems in Brazil. *Veterinary Microbiology*, *57*, 347–354.

De Oliveria, S. J., Wesley, I. V., Baetz, A. L., Harmon, K. M., Kader, I. I. T. A., & de Uzeda, M. (1999). *Arcobacter cryaerophilus* and *Arcobacter butzleri* isolated from preputial fluid of boars and fattening pigs in Brazil. *Journal of Veterinary Diagnostic Investigation*, *11*, 462–464.

Dickson, J. S., Manke, T. R., Wesley, I. V., & Baetz, A. L. (1996). Biphasic culture of *Arcobacter* spp. *Letters in Applied Microbiology*, *22*, 195–198.

Dhamabutra, N., Kamol-Rathanakul, P., & Pienthaweechai, K. (1992). Isolation of campylobacters from the canals of Bangkok. *Journal of Medical Association of Thailand*, *75*, 350–363.

Eaton, K. A., Brooks, C. L., Morgan, D. R., & Krakowka, S. (1991). Essential role of urease in pathogenesis of gastritis induced by *Helicobacter pylori* in gnotobiotic piglets. *Infection and Immunity*, *59*, 2470–2475.

Eaton, K. A., Morgan, D. R., & Krakowka, S. (1992). Motility as a factor in the colonisation of gnotobiotic piglets by *Helicobacter pylori*. *Journal of Medical Microbiology*, *37*, 123–127.

Ellis, W. A., Neill, S. D., O'Brien, J. J., Ferguson, H. W., & Hanna, J. (1977). Isolation of Spirillum/Vibrio-like organisms from bovine foetuses. *Veterinary Record*, *100*, 451–452.

Epling, L. K., Carpenter, J. A., & Blankenship, L. C. (1993). Prevalence of *Campylobacter* spp. and *Salmonella* spp. on pork carcasses and the reduction effected by spraying with lactic acid. *Journal of Food Protection*, *56*, 536–537.

Harmon, K. M., & Wesley, I. V. (1996). Identification of arcobacter isolates by PCR. *Letters in Applied Microbiology*, *23*, 241–244.

Harrass, B., Schwarz, S., & Wenzel, S. (1998). Identification and characterisation of arcobacter isolates from broilers by biochemical testsantimicrobial resistance patterns and plasmid analysis. *Journal of Veterinary Medicine Series B – Infectious Diseases and Veterinary Public Health*, *45*, 87–94.

Higgins, R., Messier, S., Daignault, D., & Lorange, M. (1999). *Arcobacter butzleri* isolated from a diarrhoeic non-human primate. *Laboratory Animals*, *33*, 87–90.

Hsueh, P. -O., Teng, L. -J., Yang, P. -C., Wang, S. -K., Chang, S. -C., Ho, S. -W., Hsieh, W. -C., & Luh, K. -T. (1997). Bacteremia caused by *Arcobacter cryaerophilus* 1B. *Journal of Clinical Microbiology*, *35*, 489–491.

Hurtado, A., & Owen, R. J. (1997). A molecular scheme based on 23S rRNA gene olymorphisms for rapid identification of campylobacter and arcobacter species. *Journal of Clinical Microbiology*, *35*, 2401–2404.

Jacob, J., Lior, H., & Feuerpfeil, I. (1993). Isolation of *Arcobacter butzleri* from a drinking water reservoir in Eastern Germany. *Zentralblatt für Hygiene und Umweltmedizin*, *193*, 557–562.

Jacob, J., Woodward, D., Feuerpfeil, I., & Johnson, W. M. (1998). Isolation of *Arcobacter butzleri* in raw water and drinking water treatment plants in Germany. *Zentralblatt für Hygiene und Umweltmedizin*, *201*, 189–198.

Johnson, L. G., & Murano, E. A. (1999a). Development of a new medium for the isolation of *Arcobacter* spp. *Journal of Food Protection*, *62*, 456–462.

Johnson, L. G., & Murano, E. A. (1999b). Comparison of three protocols for the isolation of *Arcobacter* spp. *Journal of Food Protection*, *62*, 610–614.

Kiehlbauch, J. A., Plikaytis, B. D., Swaminathan, B., Cameron, D. N., & Wachsmuth, I. K. (1991). Restriction fragment length polymorphisms in the ribosomal genes for species identification and subtyping of aerotolerant campylobacter species. *Journal of Clinical Microbiology*, *33*, 1670–1676.

Lammerding, A. M., Harris, J. E., Lior, H., Woodward, D. E., Cole, L., & Muckle, C. A. (1996). Isolation method for the recovery of *Arcobacter butzleri* from fresh poultry and poultry products. In D. G. Newall, J. Ketley, *Campylobacter VII* (pp. 329–333). New York: Plenum Press.

Lauwers, S., Breynaert, J., Van Etterijck, Revets, H., & Mets, T. (1996). *Arcobacter butzleri* in the elderly in Belgium. In D. G. Newell, J. Ketley, & R. A. Feldman, *Campylobacters, Helicobacters and Related Organisms. Proceedings of the Eighth International Conference on Campylobacters, Helicobacters and Related Organisms* (pp. 521–523). New York: Plenum Press.

Lerner, J., Brumberger, V., & Preac-Mursic, V. (1994). Severe diarrhoea associated with *A. butzleri*. *European Journal of Clinical Microbiology and Infectious Disease*, *13*, 660–662.

Manke, T. R., Wesley, I. V., Dickson, J. S., & Harmon, K. M. (1998). Prevalence and genetic variability of arcobacter species in mechanically separated turkey. *Journal of Food Protection*, *61*, 1623–1628.

Marinescu, M., Collignon, A., Squinazi, F., Woodward, D., & Lior, H. (1996a). Biotypes and serogroups of poultry strains of *Arcobacter* spp. isolated in France. In D. G. Newell, J. Ketley, & R. A. Feldman, *Campylobacters, Helicobacters and Related Organisms.*

Proceedings of the Eighth International Conference on Campylobacters, Helicobacters and Related Organisms (pp. 519–520). New York: Plenum Press.

Marinescu, M., Collignon, A., Squinazi, F., Derimay, R., Woodward, D., & Lior, H. (1996b). Two cases of persistent diarrhoea associated with *Arcobacter* spp. In D. G. Newell, J. Ketley, & R. A. Feldman, *Campylobacters, Helicobacters and Related Organisms. Proceedings of the Eighth International Conference on Campylobacters, Helicobacters and Related Organisms* (pp. 521–523). New York: Plenum Press.

Meng, J., & Doyle, M. P. (1997). Emerging issues in microbiological food safety. *Annual Review of Nutrition*, *17*, 255–275.

Musmanno, R. A., Russi, M., Lior, H., & Figura, N. (1997). In vitro virulence factors of *A. butzleri* strains isolated from superficial water samples. *Microbiologica*, *20*, 63–68.

Neill, S. D., Ellis, W. A., & O'Brien, J. J. (1978). The biochemical characteristics of *Campylobacter*-like organisms from cattle and pigs. *Research Veterinary Science*, *25*, 368–372.

Neill, S. D., Ellis, W. A., & O'Brien, J. J. (1979). Designation of aerotolerant *Campylobacter*-like organisms from porcine and bovine abortions to the genus *Campylobacter*. *Research Veterinary Science*, *27*, 180–186.

On, S. L. W., & Holmes, B. (1995). Classification and identification of *Campylobacters Helicobacters* and allied taxa by numerical analysis of phenotypic characters. *Systematic and Applied Microbiology*, *18*, 374–380.

On, S. L. W., Stacey, A., & Smyth, J. (1995). Isolation of *Arcobacter butzleri* from a neonate with bacteraemia. *Journal of Infection*, *31*, 133–138.

On, S. L. W., Holmes, B., & Sackin, M. J. (1996). A probability matrix for the identification of campylobacters, helicobacters and allied taxa. *Journal of Applied Bacteriology*, *81*, 425–432.

Phillips, C. A. (1999). The effect of citric acid, lactic acid, sodium citrate and sodium lactate, alone, and in combination with nisin, on the growth of *A. butzleri*. *Letters in Applied Microbiology*, *29*, 424–428.

Rice, E. W., Rodgers, M. R., Wesley, I. V., Johnson, C. H., & Tanner, S. A. (1999). Isolation of *A. butzleri* from ground water. *Letters in Applied Microbiology*, *28*, 31–35.

Ridsdale, J. A., Atabay, H. I., & Corry, J. E. L. (1998). Prevalence of campylobacters and arcobacters in ducks at the abattoir. *Journal of Applied Microbiology*, *85*, 567–573.

Scannell, A. G. M., Hill, C., Buckley, D. J., & Arendt, E. K. (1997). Determination of the influence of organic acids and nisin on shelf-life and microbiological safety aspects of fresh pork sausage. *Journal of Applied Microbiology*, *83*, 407–412.

Stampi, S., Deluca, G., Varoli, O., & Zanetti, F. (1999). Occurrence removal and seasonal variation of thermophilic campylobacters and arcobacter in sewage sludge. *Zentralblatt für Hygiene und Umweltmedizin*, *202*, 19–27.

Suarez, D. L., Wesley, I. V., & Larson, D. J. (1997). Detection of *Arcobacter* species in gastric samples from swine. *Veterinary Microbiology*, *57*, 325–336.

Taylor, D. N., Kiehlbauch, J. A., Tee, W., Pitarangsi, C., & Echeverria, P. (1991). Isolation of group 2 aerotolerant *Campylobacter* species from Thai children with diarrhoea. *Journal of Infectious Diseases*, *163*, 1062–1067.

Tee, W., Baird, M., Dyall-Smith, M., & Dwyer, B. (1988). *Campylobacter cryaerophilus* isolated from a human. *Journal of Clinical Microbiology*, *26*, 2469–2473.

Ursing, J. B., Lior, H., & Owen, R. J. (1994). Proposal of minimal standards for describing new species of the family *Campylobacteraceae*. *International Journal of Systematic Bacteriology*, *44*, 842–845.

Vandamme, P., & De Ley, J. (1991). Proposal for a new family *Campylobacteraceae*. *International Journal of Systematic Bacteriology*, *41*, 451–455.

Vandamme, P., Falsen, E., Rossau, R., Hoste, B., Segers, P., Tygat, R., & Delay, J. (1991). Revision of *Campylobacter*, *Helicobacter* and *Wolinella* taxonomy: emendation of generic descriptions and proposal for *Arcobacter* gen.nov. *International Journal of Systematic Bacteriology*, *41*, 88–103.

Vandamme, P., Vancanneyt, B., Pot, L., Mels, L., Hoste, B., Dewettinck, D., Vlaes, L., Van Den Borre, C., Higgins, R., Hommez, J., Kersters, K., Butzler, J. P., & Goosens, H. (1992a). Polyphasic taxonomic study of the emended genus *Arcobacter* with *Arcobacter butzleri* com.nov. and *Arcobacter skirrowii* sp. nov., an aerotolerant bacterium isolated from veterinary specimens. *International Journal of Systematic Bacteriology*, *42*, 344–356.

Vandamme, P., Pugina, P., Benzi, G., van Etterijk, R., Vlaes, L., Kersters, K., Butlzer, J. P., Lior, H., & Lauwers, S. (1992b). Outbreak of recurrent abdominal cramps associated with *A. butzleri* in an Italian school. *Journal of Clinical Microbiology*, *30*, 2335–2337.

Wesley, I. V. (1996). Helicobacter and Arcobacter species: risks for food and beverages. *Journal of Food Protection*, *59*, 1127–1132.

Wesley, I. V., Schroeder-Tucker, L., Baetz, A. L., Dewhirst, F. E., & Paster, B. J. (1995). *Arcobacter*-specific and *Arcobacter butzleri*-specific 16S rRNA-based DNA probes. *Journal of Clinical Microbiology*, *33*, 1691–1698.

Wesley, I. V., Baetz, A. L., & Larson, D. J. (1996). Infection of Cesarean-derived colostrium-deprived 1-day-old piglets with *A. butzleri, A. cryaerophilus* and *A. skirrowii*. *Infection and Immunity*, *64*, 2295–2299.

Wesley, I. V., & Baetz, A. L. (1999). Natural and experimental infections of *Arcobacter* in poultry. *Poultry Science*, *78*, 536–545.

Zanetti, F., Varoli, O., Stampi, S., & De Luca, G. (1996). Prevalence of thermophilic *Campylobacter* and *Arcobacter butzleri* in food of animal origin. *International Journal of Food Microbiology*, *33*, 315–321.