

Journal of the Hellenic Veterinary Medical Society

Vol 67, No 2 (2016)



Campylobacter spp. infection in humans and poultry

G. NATSOS, K. C. KOUTOULIS, E. SOSSIDOU, M. CHEMALY, N. K. MOUTTOTOU

doi: [10.12681/jhvms.15624](https://doi.org/10.12681/jhvms.15624)

Copyright © 2018, G NATSOS, KC KOUTOULIS, E SOSSIDOU, M CHEMALY, NK MOUTTOTOU



This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0](https://creativecommons.org/licenses/by-nc/4.0/).

To cite this article:

NATSOS, G., KOUTOULIS, K. C., SOSSIDOU, E., CHEMALY, M., & MOUTTOTOU, N. K. (2018). Campylobacter spp. infection in humans and poultry. *Journal of the Hellenic Veterinary Medical Society*, 67(2), 65–82. <https://doi.org/10.12681/jhvms.15624>

Campylobacter spp. infection in humans and poultry

Natsos G.¹, Koutoulis K.C.¹, Sossidou E.², Chemaly M.^{3,4}, Mouttotou N.K.⁵

¹*Department of Poultry Diseases, Faculty of Veterinary Science, University of Thessaly, Karditsa*

²*Hellenic Agricultural Organization - Demeter, Veterinary Research Institute, Thessaloniki*

³*Anses, Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, UHQAP, Unité Hygiène et Qualité des produits avicoles et porcins BP 53, 22440 Ploufragan, France*

⁴*UEB: Université Européenne de Bretagne*

⁵*Ministry of Rural Development and Foods, National Reference Laboratory of Salmonella and Antimicrobial Resistance, Chalkida*

Μόλυνση με Campylobacter spp. στους ανθρώπους και τα πτηνά

Νάτσος Γ.¹, Κουτουλής Κ.Χ.¹, Σωσσίδου Ε.², Chemaly Μ.^{3,4}, Μουττωτού Ν.Κ.⁵

¹*Κλινική Παθολογία Πτηνών, Τμήμα Κτηνιατρικής, Σχολή Επιστημών Υγείας, Πανεπιστήμιο Θεσσαλίας*

²*Ελληνικός Γεωργικός Οργανισμός – Δήμητρα, Ινστιτούτο Κτηνιατρικών Ερευνών, Θεσσαλονίκη*

³*Anses, Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail, UHQAP, Unité Hygiène et Qualité des produits avicoles et porcins BP 53, 22440 Ploufragan, France.*

⁴*UEB: Université Européenne de Bretagne*

⁵*Υπουργείο Αγροτικής Ανάπτυξης & Τροφίμων, Εθνικό Εργαστήριο Αναφοράς Σαλμονελλώσεων και Μικροβιοαντοχής, Χαλκίδα*

ABSTRACT. Campylobacter is well recognized as the leading cause of bacterial foodborne diarrheal disease worldwide. The infection may be subclinical or cause disease of variable severity. The eating and handling of improperly cooked or raw broiler meat has been shown to be one of the most important sources of human campylobacteriosis. Birds carrying Campylobacter are asymptomatic colonizers without any clinical signs. Broilers are considered Campylobacter free after hatching and become colonized by exposure to viable bacteria from the environment. Several risk factors can result in the introduction of Campylobacter into the flocks making it difficult to keep chicken flocks free of Campylobacter throughout the rearing period. Lack of biosecurity measures, season, age, partial depopulation practices, flock size, type of production system, presence of other animals on farm, water quality, presence of rodents and mechanical transmission via insects are considered to be some of the risk factors associated with horizontal transmission. The control of

Corresponding author: Konstantinos C. Koutoulis,
Department of Avian Pathology, Faculty of Veterinary Science, University of Thessaly,
Triakalon 224, 43100, Karditsa, kkoutoulis@vet.uth.gr

Date of initial submission: 12.04.2014
Date of revised submission: 12.05.2014
Date of acceptance: 14.05.2014

Campylobacter in poultry seems crucial for the reduction of human campylobacteriosis cases. In Greece, there has been a dearth of information on prevalence and risk factors of *Campylobacter* in broiler flocks. Therefore, it is essential to initially investigate the prevalence of *Campylobacter* infection on farms and in poultry carcasses and subsequently the risk factors at all production stages of broiler meat and plan intervention studies to help reducing the disease in humans. This paper review the most recent data reported worldwide on *Campylobacter* infection in humans and poultry in order to provide an overview of trends, risks, possible causes and mechanisms of transmission routes.

Keywords: broilers, *Campylobacter*, campylobacteriosis, foodborne pathogens, Greece, poultry, prevalence, risk factors

ΠΕΡΙΛΗΨΗ. Το *Campylobacter* είναι παγκοσμίως αναγνωρισμένο ως η κύρια αιτία της διαρροϊκής, βακτηριακής αιτιολογίας, τροφοδηλητηρίασης. Η μόλυνση μπορεί αν είναι υποκλινικής μορφής ή να προκαλεί ασθένεια διαφορετικής σοβαρότητας. Η κατανάλωση και ο χειρισμός του πλημμελώς μαγειρεμένου ή ωμού ορνίθιου κρέατος έχει αποδειχθεί ως μία από τις πιο σημαντικές πηγές της ανθρώπινης καμπυλοβακτηρίωσης. Τα πτηνά που μεταφέρουν το *Campylobacter* είναι ασυμπτωματικοί φορείς, χωρίς κλινικά συμπτώματα. Τα ορνίθια κρεοπαραγωγής θεωρούνται ελεύθερα από *Campylobacter* μετά την εκκόλαψη και μολύνονται με την έκθεση τους στα βακτήρια από το περιβάλλον. Αρκετοί παράγοντες κινδύνου μπορούν να οδηγήσουν στην μόλυνση των σμηνών από *Campylobacter*, γεγονός που καθιστά πολύ δύσκολο να μείνουν τα σμήνη των πτηνών απαλλαγμένα καθ' όλη τη διάρκεια της εκτροφής. Η έλλειψη μέτρων βιοασφάλειας, η εποχή, η ηλικία, πρακτικές αραίωσης του πληθυσμού, το μέγεθος του σμήνους, το είδος του συστήματος παραγωγής, η παρουσία άλλων ζώων στην εκμετάλλευση, η ποιότητα των υδάτων, η παρουσία τροφικών και η μηχανική μετάδοση μέσω εντόμων θεωρούνται μερικοί από τους παράγοντες κινδύνου που συνδέονται με την οριζόντια μετάδοση. Ο έλεγχος του *Campylobacter* στα πτηνά είναι πολύ σημαντικός για τη μείωση των περιστατικών της καμπυλοβακτηρίωσης στους ανθρώπους. Στην Ελλάδα, υπάρχει έλλειψη δεδομένων σχετικά με τον επιπολασμό και τους παράγοντες κινδύνου του *Campylobacter* στα σμήνη ορνιθίων κρεοπαραγωγής. Έτσι, είναι πολύ σημαντικό να διερευνηθεί αρχικά, ο επιπολασμός του *Campylobacter* στις πτηνοτροφικές εκμεταλλεύσεις και στα σφάγια πουλερικών και στη συνέχεια, οι παράγοντες κινδύνου σε όλα τα στάδια της παραγωγής του ορνίθιου κρέατος, έτσι ώστε να σχεδιαστούν μελέτες παρέμβασης που θα βοηθήσουν να μειωθούν τα περιστατικά της ασθένειας στον άνθρωπο. Η εργασία αυτή κάνει μια ανασκόπηση των πιο σύγχρονων δεδομένων που έχουν αναφερθεί παγκοσμίως για τη μόλυνση με *Campylobacter* στους ανθρώπους και τα πτηνά προκειμένου να προσφέρει μια επισκόπηση των τάσεων, των παραγόντων κινδύνου, τις πιθανές αιτίες και των μηχανισμών των οδών μετάδοσης.

Λέξεις ευρετηρίασης: ορνίθια κρεοπαραγωγής, *Campylobacter*, καμπυλοβακτηρίωση, τροφιμογενή παθογόνα, Ελλάδα, πτηνά, επιπολασμός, παράγοντες κινδύνου

INTRODUCTION

Human campylobacteriosis is considered an important public health problem and poultry has been identified as a significant source for human infections with *Campylobacter* species. Although thermophilic *Campylobacter* spp. are not significant pathogens for poultry, they are of importance to food safety and public health, with *C. jejuni* being responsible for the majority of human campylobacteriosis, followed by *C. coli*, and rarely by *C. lari* (Zhang and Sahin, 2013).

Other *Campylobacter* species, such as *C. upsaliensis* and *C. fetus*, may also be associated with human diarrhea. Although the detection of non-*C. jejuni/coli* is uncommon in human cases in the industrialized world, it is more common in the developing world (Lastovica and Allos, 2008). This paper review the most recent data reported worldwide on *Campylobacter* infection in humans and poultry in order to provide an overview of trends, risks, possible causes and mechanisms of transmission routes.

CAMPYLOBACTERIOSIS AND PUBLIC HEALTH

Incidence, severity and costs

Since 1990's the incidence of human campylobacteriosis has been steadily rising worldwide (Baker et al., 2007; WHO, 2011; EFSA, 2014). This is in accordance with the Community Zoonoses Reports of the European Food Safety Authority (EFSA) and the European Centre for Disease Prevention and Control (ECDC). In the EU, campylobacteriosis has been the most commonly reported zoonosis since 2005, followed by salmonellosis (EFSA, 2006; EFSA, 2014). Information submitted by 27 European Union Member States (EU MS) on the occurrence of zoonoses and food-borne outbreaks in 2012, showed that there were 214,268 confirmed human cases of campylobacteriosis (EFSA, 2014). Thus, the overall notification rate of human campylobacteriosis was 55.49 per 100,000 population (range: 0.39 - 174.08 per 100,000 population). There was a wide variation in incidences between countries which probably reflects differences in the healthcare and reporting systems, and in microbiological methods for the detection of *Campylobacter* (Olson et al., 2008; Vally et al., 2009; EFSA, 2014). Even though clinical cases of campylobacteriosis tended to be under-reported, "there may be not less than 2 million and possibly as high as 20 million cases of clinical campylobacteriosis per year in the 27 EU MS" (EFSA, 2010c). The number of confirmed cases of campylobacteriosis in the European Union has followed a statistically significant ($p < 0.001$) increasing trend in the last five years (2008-2012), along with a clear seasonal trend (summer months) (EFSA, 2014). Considering the high number of human campylobacteriosis cases, the severity in terms of reported fatalities was low (0.03%) (EFSA, 2014).

According to Scallan et al (2011) *Campylobacter* is the third-leading cause of bacterial foodborne illness in the United States. Information provided by the Foodborne Diseases Active Surveillance Network (FoodNet) of the Centers for Disease Control and Prevention (CDC), from 10 State Health Departments in the USA, indicated campylobacteriosis as the second most common infection (35%), following salmonellosis (40%). CDC also estimated that in 2012, the number of reported infections and incidence per 100,000 population by *Campylobacter* was 6,793 and 14.30, respec-

tively (CDC, 2013). In the same report the estimated incidence of infection for *Campylobacter* showed a 14% increase in 2012, compared with 2006–2008. Also, in the USA, it is estimated that *Campylobacter* causes 2.5 million illnesses, 13,000 hospitalizations, and over 100 deaths each year (Patrick, 2007).

In Australia, *Campylobacter* is currently the most common cause of acute bacterial diarrhea among all the notified enteric pathogens with more than 15,000 cases each year (Stafford, 2010). The incidence of notified campylobacteriosis has steadily increased during the past 15 years from 67.0/100,000 population in 1991 to 121.4/100,000 in 2005 (Stafford, 2010). According to the same researcher, adjusting for under-reporting, there may be an estimation of 225,000 infections occurring each year in Australia, but most of which are sporadic in nature.

In many developing areas of the world, human campylobacteriosis is hyperendemic and the disease differs from campylobacteriosis in developed countries (Coker et al., 2002). In developing areas, campylobacteriosis is predominantly a pediatric problem affecting children under the age of five while adults are generally less prone to the disease (Oberhelman and Taylor, 2000; Coker et al., 2002). Generally, developing countries do not have national surveillance programs for campylobacteriosis; therefore, incidence values in terms of number of cases for a population do not exist (Coker et al., 2002). Most estimates of incidence came from laboratory-based surveillance of pathogens responsible for diarrhea. Oberhelman & Taylor (2000) estimated that *Campylobacter* isolation rates in developing countries ranged from 5 to 20%. In Asiatic countries like Thailand for example, the overall isolation rate of *Campylobacter* from diarrheal children under year 5 was 6.8% (Yang et al., 2008). This rate was 12.1% in Laos, with *C. jejuni* and *C. coli* occurring in 7.1% and 4% of enteric infection in children aged < 1 year and 1–5 years, respectively (Yamashiro et al., 1998).

There are no sufficient data on campylobacteriosis in Greece, because the disease is not under surveillance through Mandatory Notification System. According to Hellenic Center for Disease Control & Protection (HCDCP) factsheet of 2013, although there are few hospitals with laboratory ability of *Campylobacter* isolation, the number of positive cultures for this pathogen was high (623 positive cultures) in 2012, even

greater than the frequency of salmonellosis (HCDCP, 2013). These data indicate the need of integration of campylobacteriosis on the Mandatory Notification System in order to achieve full illustration of the morbidity caused by the microorganism in question and the need of setting a specialized reference laboratory. Nevertheless, there have been several references about *Campylobacter* spp. and its contribution on acute gastroenteritis among patient in Greek hospitals, especially children (Kafetzis et al., 2001; Maltezou et al., 2001; Chatzipanagiotou et al., 2002; Chatzipanagiotou et al., 2003a; Maraki et al., 2003; Ioannidis et al., 2006; Papavasileiou et al., 2007; Ioannidis et al., 2009; Maragkoudakis et al., 2010; Mellou et al., 2010; Mammias et al., 2012; Maraki et al., 2012; Ioannidis et al., 2013). Moreover, the first diagnosed *C. jejuni*-associated Guillain-Barré Syndrome case from Greece in 2003 reported by Chatzipanagiotou et al. (2003b).

Human infections with *Campylobacter* pathogenic strains are characterized by nausea, vomiting, stomachache, malaise, profuse watery diarrhea, blood in feces and high fever (Blaser et al., 2008). The infective dose of campylobacteriosis can be as low as few hundred cells (Black et al., 1988). In most cases the illness is self-limiting, but it may be severe and life threatening in susceptible people such as young children, the elderly, or people with immunosuppressive diseases, such as AIDS and cancer (EFSA, 2011). In cases where antibiotic treatment is needed, fluoroquinolones and erythromycin are considered the drugs of choice, but attention should be paid since a rapidly increasing proportion of *Campylobacter* strains all over the world have been found to be resistant to these antibiotics (Allos, 2001; EFSA 2013b). The incubation period is up to 10 days with typical symptoms related to enteritis, with diarrhea, cramps, abdominal pain and fever. In susceptible humans, *C. jejuni/coli* infection is associated with acute enteritis and abdominal pain lasting for up to seven days or longer (Allos, 2001). Infection is sometimes complicated by the development of serious post infection complications, such as bacteraemia, Guillain-Barré syndrome (GBS), reactive arthritis, inflammatory bowel disease, irritable bowel syndrome (Allos, 2001; Helms et al., 2003; Havelaar et al., 2005; Mangen et al., 2005; Smith and Bayles, 2007; Gradel et al., 2009; Haagsma et al., 2010) and even death (Havelaar et al., 2005; Gradel et al., 2008). GBS is an acute demyelinating disease of the periph-

eral nervous system resulting in temporary ascending flaccid paralysis (Allos, 2001). There are enough data on the incidence of GBS in Europe and North America (McGrogan et al., 2009; Sejvar et al., 2011). The disease has also been well studied in China, where it may implicate in outbreaks, and in Japan, whereas seasonal patterns of GBS have been described in Mexico, China, Argentina, Curacao, South Africa and other countries (Coker et al., 2002; WHO, 2013).

The socioeconomic costs of the disease in humans can be very high (Samuel et al., 2004) and this is expected, if one takes under consideration that there may be approximately nine million cases of human campylobacteriosis per year in the 27 EU MS (EFSA, 2011). The public health impact of campylobacteriosis and its sequelae is 0.35 million disability-adjusted life years (DALYs) per year and total annual costs are 2.4 billion euros (EFSA, 2011). These costs reflect to medical expenses, lost wages, product recalls, legal costs, and other indirect expenses (CAST, 1994). Havelaar et al. (2005), estimated that in the Netherlands (with approximately 80,000 cases of gastroenteritis per year), the costs of illness caused by campylobacteriosis are about 21 million euros / year.

Outbreaks of *Campylobacter* spp. - Sources and transmission of infection

Most campylobacteriosis cases are sporadic or small-scale family outbreaks (Olson et al. 2008). Even though outbreaks of *Campylobacter* infections are rarely reported, they might be more common than previously suspected (Gillespie et al., 2003; Miller et al., 2004; Fussing et al., 2007; Isohanni, 2013). Because the incubation period before the onset of symptoms can be long, it might be difficult to determine the source of infection. Numerous epidemiological studies have been conducted to identify potential sources for human campylobacteriosis. Most cases of outbreaks in the literature were associated with handling raw poultry, eating raw or undercooked poultry meat or cross-contamination of raw to cooked foods (Tauxe et al., 1997; Studahl and Andersson, 2000; Corry and Atabay, 2001; Nadeau et al., 2002; Kapperud et al., 2003; Neimann et al., 2003; Nielsen et al., 2006; Stafford et al., 2007; Doorduyn et al., 2010; EFSA, 2014). The consumption of chicken and chicken by-products has been increased due to their low price, special taste, and the short

time required for preparation and consequently they have been implicated over the recent years in a large number of outbreaks of acute campylobacteriosis in human populations worldwide, in both industrialized and developing countries, and especially in children, the elderly and immuno-suppressed patients (Skirrow, 1998; Corry and Atabay, 2001). In particular, the handling, preparation and consumption of broiler meat accounted for 20% to 30% of campylobacteriosis cases, while 50% to 80% attributed to the chicken reservoir as a whole (EFSA, 2010c). Furthermore, broiler meat was the most commonly implicated food vehicle, accounting for 11 of the 25 strong-evidence outbreaks (44.0%) (EFSA, 2014).

Other possible sources of campylobacteriosis include other contaminated food, contaminated water, direct contact with farm animals, environmental sources and foreign travel. According to EFSA's report for 2012, among 19 EU MSs a total of 501 foodborne *Campylobacter* outbreaks were reported and this counted for 9.3 of the total reported foodborne outbreaks in the EU (EFSA, 2014).

Besides broiler meat, contaminated livers constitute a notable source of human campylobacteriosis. Outbreaks of *Campylobacter* infections linked to chicken and duck liver pâté have been reported in the United Kingdom (O'Leary et al., 2009), Australia (Parry et al., 2012), Europe (EFSA, 2013a) and USA (Tompkins et al., 2013). In addition, since 2007, England and Wales have mentioned a significant increase in the proportion of *Campylobacter* outbreaks linked to the consumption of chicken livers used in pâté (Little et al., 2010). These outbreaks did not come as a surprise, given that previous studies had shown that 77% of retail chicken livers were contaminated with *Campylobacter* (Little et al., 2010).

Some researchers point out eggs as a possible route of transmission since fecal contamination of the shell may take place and the survival of *Campylobacter* on eggshell is being promoted by the shell's moisture (Cox et al., 2012). In a study conducted by Messelhäusser et al. (2011) viable bacteria of *Campylobacter* spp. were found in 4.1% of the eggshell samples, whereas Jones and Musgrove (2007) found 0.5% of the restricted shell eggs investigated positive for thermotolerant *Campylobacter* spp. In Japan, Sato and Sashihara (2010) found that between 27.9 and 36% of unpasteurized liquid egg

samples were positive for *Campylobacter*. Therefore, a contaminated eggshell always creates the risk of cross-contaminating the egg yolk with pathogens and of initiating food-borne infections by producing ready-to-eat food with raw or undercooked egg content. The other possibility is cross-contamination from the eggshell to other ready-to-eat products which do not contain the egg content itself (Cox et al., 2012).

In addition to risks from food, contact with animals, either domestic pets or farm animals, presents another exposure pathway for human infection (Saeed et al., 1993; Schorr et al., 1994; Studahl and Andersson, 2000; Moore et al., 2005). Other foods (such as pork, beef and unpasteurized milk), or direct contact with these animals were mentioned in the literature as pathways to acquire *Campylobacter* infection (Moore et al., 2005; Jacobs-Reitsma et al., 2008). The digestive tract of healthy cattle can be a significant reservoir for a number of *Campylobacter* species, with a prevalence of the enteropathogen in cattle ranging from 0–80% (Atabay and Corry, 1998) whereas the prevalence of *Campylobacter* spp. in sheep was about 20% (Zweifel and Stephan, 2004). Pig carcasses have been shown to be more frequently contaminated than either beef or sheep (Nesbakken et al., 2003). This is most likely attributable to the fact that pig carcasses undergo a communal scalding stage early in the slaughtering process combined with the fact that the skin remains on the carcass following all of the dressing procedures (Moore et al., 2005).

Raw milk has also been identified as a vehicle of human gastroenteritis caused by *Campylobacter* spp. (Weltman et al., 2013; EFSA, 2014). Especially, *C. jejuni* was found to be present in milk due to faecal cross-contamination during milking or as a result of udder infection (Orr et al., 1995).

Waterborne outbreaks of *Campylobacter* have been reported in many developed countries (Allos, 2001; Martin et al., 2006; Jakopanec et al., 2008; EFSA, 2013a).

In Greece, a waterborne *Campylobacter jejuni* outbreak occurred in Crete in 2009. Most cases originated from rural areas, served by a different water-supply system from that of the adjacent town and there was strong epidemiological evidence that tap water was the vehicle of the outbreak (Karagiannis et al., 2010a, Karagiannis et al., 2010b). Consumption of untreated

water (Schorr et al., 1994) or rainwater (Eberhart-Phillips et al., 1997) was associated with campylobacteriosis in other studies. In an ecological study in Sweden, positive associations were found between the incidence of *Campylobacter* spp. and the average volume of water consumed per person. These observations suggested that drinking water and contamination from livestock might also be important factors in explaining at least a proportion of human sporadic campylobacteriosis cases (Nygard et al., 2004).

Contaminated shellfish have also been implicated as a vehicle in the dissemination of campylobacteriosis. Harvesting shellfish from *Campylobacter*-contaminated waters would appear to be the most likely cause of infection (Wilson & Moore, 1996).

Travel to a developing country is a risk factor for acquiring *Campylobacter*-associated diarrhea, which is more severe, and strains are more likely to be associated with antibiotic resistance (Coker et al., 2002). Campylobacteriosis acquired abroad contributes to the number of cases reported in developed countries and, as a result, represents an important subset of all cases. In the USA, 13% of *Campylobacter* infections are associated with international travel, and *Campylobacter* is the most frequently reported travel-associated infection (Kendall et al., 2012). In Scandinavia, the proportion of travel-related cases is higher, and systematic reporting of such infections has provided proxy surveillance information for parts of the world where diagnostic testing or reporting of the infection is less frequent (Ek Dahl and Andersson, 2004).

CAMPYLOBACTER IN BROILER PRODUCTION

Broiler farms

Broiler intestines are a particularly favorable environment for the proliferation of thermophilic *Campylobacter*s, such as *C. jejuni* and *C. coli*. Birds carrying *Campylobacter* are asymptomatic colonizers without any clinical signs (Lee & Newell, 2006). Broilers are considered *Campylobacter* free after hatching, since most evidence suggest that vertical transmission plays a minor role, if any (Jacobs-Reitsma et al., 1995; Pearson et al., 1996; Petersen & Wedderkopp, 2001; Sahin et al., 2003; Callicott et al., 2006) and

in general, broiler flocks remain *Campylobacter* free for the first two weeks (Annan-Prah & Janc, 1988; Stern, 1992). Nevertheless, Cox et al. (2012) referred to trans-ovarian transmission since fecal bacteria, including *Campylobacter*, can contaminate the shell, shell membranes, and albumen of freshly laid eggs and the chick can become colonized after ingestion of the pathogen when it emerges from the egg. After the first colonization (usually at two to three weeks of age), following exposure to viable bacteria from the environment, *Campylobacter* spread quickly within the flock. The presence of *Campylobacter* in the caeca can be at a detectable level few hours after the exposure (Bull et al., 2006), while birds remain highly colonized until slaughter (Berndtson et al. 1996a, van Gerwe et al. 2009), representing an important public health risk.

The prevalence of *Campylobacter* in broiler flocks varies among different countries. A harmonized baseline survey was conducted in the EU in 2008, generating representative data regarding national production, in order to estimate the prevalence of *Campylobacter* in broilers and on broiler meat (EFSA, 2010a). Approximately 71.2% of broiler batches were estimated to be colonized by *Campylobacter* at the slaughterhouse. The prevalence of *Campylobacter*-colonized broiler batches among the EU member states varied widely, ranging from as low as 2.0% up to 96.8% (EFSA 2010a). The results of the EU baseline survey were consistent with several other studies (Rasschaert et al., 2007; Allen et al., 2008; Kuana et al., 2008; Hue et al., 2010; Hue et al., 2011; Lawes et al., 2012; Powell et al., 2012). In 2012, the overall proportion of *Campylobacter*-positive broiler flocks was 33.56 % (range: 0 % - 83.6 %) among the five MSs (e.g. Denmark, Germany, Hungary, Slovenia, Sweden) which reported flock-based data (EFSA, 2014). Several other flock-based studies have showed a prevalence from 15% up to 76% (Barrios et al., 2006; Arseunault et al., 2007a; Guerin et al., 2007; McDowell et al., 2008; Sasaki et al., 2010; Ansari-Lari et al., 2010)

Campylobacter jejuni is the predominant species isolated from poultry samples, followed by *C. coli*, with other *Campylobacter* species such as *C. lari* being less detected. In the southern EU MSs the presence of *C. coli* was more abundant, whereas *C. jejuni* was the only species isolated in the northern countries (EFSA, 2010a). Climatic conditions, environmental reservoirs, broiler housing and age of slaughter that vary significantly from northern to southern Europe

could partly explain the observed variation of the species distribution (EFSA, 2010a). In addition, *C. coli* is more frequently identified in older animals and particularly from organic systems (El-Shibiny et al., 2005). Some studies mention that *C. coli* is more commonly isolated from poultry in the developing world. Specifically, *C. coli* was the dominant *Campylobacter* species isolated from poultry in Nigeria and Thailand (Aboaba and Smith, 2005; Padungtod and Kaneene, 2005). Poultry flocks and individual chickens might be infected with different *Campylobacter* strains at the same time (Jacobs-Reitsma et al., 1995; Rivoal et al., 1999). Furthermore, mixed infections can result in new strains through the exchange of genetic material (Jacobs-Reitsma et al., 1995; De Boer et al., 2002; Hook et al., 2005).

There is a paucity of data about the prevalence of *Campylobacter* spp. in broiler flocks in our country since Greece did not participated in the European union-wide baseline survey carried out in 2008. The isolation, identification, and antimicrobial resistance of *Campylobacter* spp. from poultry farms and slaughter houses has been investigated and reported for the first time in Greece by Marinou et al (2013). The results of this study showed a low prevalence (16/830 (1.9%) fecal samples) of *Campylobacter* spp. in five poultry farms in a geographical region around Athens, with the predominance of *C. coli*. However, the need for a surveillance and monitoring system for the prevalence, risk factors and antimicrobial resistance of *Campylobacter* in poultry and other food animals is a requisite and more studies about this topic should be carried out.

The incidence and prevalence of *Campylobacter* in positive broiler flocks varies depending on geographical, farming and environmental conditions. Seasonality effects have been observed with a marked peak during summer months, much more noticeable in Northern Europe (Bouwknegt et al., 2004; Patrick et al., 2004; Hofshagen and Kruse, 2005; Hansson et al., 2007; van Asselt et al., 2008; Jore et al. 2010; Zoonosis Centre, 2012;) than in Southern Europe (Nylen et al., 2002). In contrast, some studies in the United Kingdom, USA, and Canada have reported no seasonal influence on *Campylobacter* prevalence (Humphrey et al., 1993; Gregory et al., 1997; Nadeau et al., 2002). Seasonality effects could be explained by environmental factors, which require further investigation, such as humidity, temperature and sunlight (Wallace et al., 1997; Arse-

nault et al., 2007a; Guerin et al., 2008). For instance, a warmer mean temperature and the moister climate during summertime provide conditions favoring environmental *Campylobacter* survival, as well as increase the amount of insects, wild birds and rodents, which act as mechanical vectors for the pathogen, around the broiler house (Hald et al. 2004, Rushton et al. 2009, Jore et al. 2010). Except of the abundance of flies, the increased ventilation because of higher temperatures during the summer has also been related to the seasonal variation (Hald et al., 2008). It has been also claimed, that in the Nordic countries, the cold winters contribute to the decrease of the *Campylobacter* environmental load.

Remarkably, the increase in human cases can sometimes occur previous to infections in chickens, suggesting that there might be a common risk factor responsible for the increase in *Campylobacter* cases. Flies can transmit *Campylobacter* to chickens and humans and they could partly explain the seasonality of human cases (Hald et al., 2004; Nichols, 2005; Ekdahl et al., 2005; Nelson et al., 2006; Guerin et al., 2008; Hald et al., 2008; Nichols, 2010).

Broiler slaughterhouses - Carcasses

The intestinal colonization of broilers with *Campylobacter* during rearing is responsible for the contamination of the carcasses and equipment with *Campylobacter* during slaughtering (Rosenquist et al. 2006, Reich et al. 2008; Silva et al., 2011). Food processing areas that constitute critical control points in poultry processing plants are usually scalding, defeathering and evisceration, since the carcass contamination occurs there by leakage of the contaminated faeces from the cloaca and visceral rupture of the ceca carrying a high *Campylobacter* load (Berrang et al., 2001; Stern & Robach, 2003; Takahashi et al., 2006; Boysen & Rosenquist, 2009; Silva et al., 2011). Automated defeathering represents a high risk practice since cloacal contents can cause contamination of the carcasses (Berrang et al., 2001). *Campylobacter* spp. remain in a liquid film on the skin and become entrapped in its cervices and channels which provides a favourable environment for cross contamination (Chantarapanont et al., 2003). Cross-contamination of *Campylobacter* strains between slaughtered flocks may also occur via contacts with contaminated surfaces of the slaughter facilities, processing water and air (Peyrat et al. 2008,

Perko-Mäkelä et al. 2009; Isohanni, 2013). Furthermore, the persistence and survival of *Campylobacter* spp. are fostered by a suitable microenvironment of the skin (Chantarapanont et al., 2003) and even under frozen conditions or storage at 4°C, *Campylobacter* spp. are able to persist in the carcass (Maziero and de Oliveira, 2010). Previous studies reported that growth on skin stored at room temperature in a controlled atmosphere package is possible, increasing the risk for consumers if contaminated chicken is not adequately stored or handled (Lee et al., 1998; Scherer et al., 2006). It has been found that carcasses from batches with *Campylobacter*-positive caeca have significantly higher quantitative loads than those from batches with negative caeca, which is in accordance with other studies, indicates that reduction in intestinal contamination could be a possible way to reduce the amount of bacteria on carcasses (EFSA, 2010a; Hue et al. 2011).

The average prevalence of *Campylobacter* contamination on broiler carcasses worldwide is reported to be in the range of 60-80% (Suzuki & Yamamoto, 2009; Isohanni, 2013). According to EFSA (2010a), the prevalence in the EU of *Campylobacter*-contaminated broiler carcasses, in 2008, was reported as 75.8% and varied from 4.9% to 100.0% among the EU MSs. That prevalence is higher than the respective prevalence for broiler batches, which come into accordance with the results of other studies (Hue et al., 2011; Powell et al., 2012; Chokboonmongkol et al., 2013), assuming that cross-contamination from positive batches to negative batches does occur during the slaughtering process and associated carcass preparation (Jørgensen et al. 2002; Johannessen et al. 2007; EFSA, 2010a; Hue O. et al, 2011) through contamination of the slaughterhouse environment (Johnsen et al 2006). The counts of *Campylobacter* bacteria on broiler carcasses varied widely also between countries, which might be due to differences in slaughterhouse hygiene and processing practices (Habib et al., 2008; Sampers et al., 2008; EFSA, 2010a). In general there was a tendency for high counts in countries with high *Campylobacter* prevalence. Low *Campylobacter* numbers on broiler carcasses may reflect effective pre-harvest production procedures, good slaughter hygiene, low within-flock prevalence or low cross-contamination of carcasses of a *Campylobacter*-negative batch from a previous positive batch (Johannessen et al. 2007). The elevated levels of *Campylobacter* can be recovered from the

broiler carcasses and transmitted in the food chain during further processing (EFSA 2010a).

The distribution of *Campylobacter* species isolated from broiler carcasses varies among different countries. *Campylobacter jejuni* proved to be the predominant species at EU level, with about two-thirds of the total isolates being identified as *C. jejuni*, while approximately one-third was *C. coli*. Other *Campylobacter* species are less frequently identified (EFSA, 2010a). Still, the reverse situation was observed in some MSs reporting dominance of *C. coli* isolates. Moreover, a high proportion of *C. coli* in poultry meat has been reported from some other parts of the world (Meeyam et al., 2004; Padungtod et al., 2005; van Nierop et al., 2005; Suzuki & Yamamoto, 2009). In Greece, no information is available, since there is no surveillance and monitoring system. According with the study performed by Marinou et al. (2013), no *Campylobacter* was isolated from the cecal samples of the chicken carcasses.

Retail broiler meat products

Broiler meat is considered to be the main food-borne source of human campylobacteriosis. According to EFSA (2014), a large share of retail broiler meat remains contaminated with *Campylobacter*. In 2012, approximately 30% of the samples of poultry meat in retail were found to be positive in the 9 EU MSs reporting data on testing of single broiler samples, (range: 0% - 80.6%). The reported levels of *Campylobacter* in fresh broiler meat products at retail vary between log 1 to log 4 cfu/100 g (or a fillet) of meat, depending on the different studies and methodologies used (Jacobs-Reitsma et al., 2008). Studies report that *C. jejuni* was usually the dominant *Campylobacter* species isolated from retail broiler meat products worldwide, but the ratio of *C. coli* to *C. jejuni* varied between countries (Suzuki and Yamamoto, 2009). Limited studies have been published on the prevalence of *Campylobacter* in broiler meat at the Greek retail level. The presence of *Campylobacter* spp. in poultry meat, along with isolation, identification at species level and determination of the antibiotic resistance of the isolates has been investigated by Petridou and Zdragas (2009) in Northern Greece. The results of Petridou & Zdragas study showed that 73% of the samples were *Campylobacter* positive, while *Campylobacter jejuni* seemed to be the predominant species. Moreover, the prevalence

of *Campylobacter* spp. in raw broiler meat was investigated by Zisidis (2011) during the period from 2005 to 2010. The samples were collected from several slaughterhouses, poultry meat selling points and restaurants of Western Greece. The results showed that 28.7% of the samples were *Campylobacter* positive, with *C. jejuni* as predominant species and a remarkable decline of positive results was observed through the study from 50% in 2005 to 18.5% in 2010. However, there is still a need of more investigation in order to determine the true prevalence of *Campylobacter* spp. in our country.

Risk factors associated with *Campylobacter* spp. colonization in broiler flocks and broiler carcasses contamination

Several risk factors can result in the introduction of *Campylobacter* into the flocks making it difficult to keep chicken flocks free of *Campylobacter* throughout the rearing period. The possible sources and transmission routes of *Campylobacter* for poultry flocks have been investigated extensively, focusing on different parts of the production processes and practices. Most epidemiological studies have focused on the outcome being the flock becoming infected, not considering the within flock prevalence nor the amount of *Campylobacter* in the infected chickens. The outside environment has been suggested as the ultimate source of colonization for broiler flocks. In addition, many factors - such as adjacent broiler units or other animals, farm workers, drinking water, rodents, wild birds, flies and other insects - may have a role in transmitting *Campylobacter* to broiler flocks (Hald et al. 2004, Bull et al. 2006, Rushton et al. 2009).

The most important risk factors associated with horizontal transmission of *Campylobacter* spp. to broiler flocks and broiler carcass contamination during the slaughtering process are shown in *Table 1* and *Table 2* respectively.

Controlling of *Campylobacter* spp. infection through active surveillance

Burden of disease studies provide evidence that there is a need for control measures across all outcomes of campylobacteriosis while taking into consideration its underestimation (WHO, 2013). Nowadays, the implementation of effective controls to reduce the

burden of disease in humans is considered a priority in many areas of the world. Consequently, the control of *Campylobacter* in poultry seems crucial for the reduction of human campylobacteriosis cases.

European Food Safety Authority has emphasized the importance and recommended the establishment of an active surveillance of campylobacteriosis in all MS, including efforts to determine the uncertain and unreported campylobacteriosis cases. In addition, storage and genotyping of human and putative reservoirs of isolates in all MS have also been recommended (EFSA, 2011). Thereafter, it would be important to identify the *Campylobacter* properties of virulence, survival characteristics and ecology (EFSA, 2011).

CONCLUDING REMARKS

In conclusion, the necessity to study the prevalence of the disease in the poultry population and identify the risk factors associated with this in Greece should be stressed. The cross sectional study which is currently being carried out in Greece, will give important information on prevalence of *Campylobacter* infection in poultry production and will be the foundation in understanding the epidemiology of the microorganism countrywide.

ACKNOWLEDGMENTS

The project “*Campylobacter* spp. in the broiler food chain: Measuring and monitoring the risk for public health” is granted by the “General Secretariat of Research and Technology” - Ministry of Education and Religious Affairs - under the “Bilateral Cooperation R&T Program between Greece and France 2013”.

The authors would like to thank the Ministry of Rural Development and Foods, National Reference Laboratory of Salmonella and Antimicrobial Resistance of Chalkida, for its contribution in the isolation and detection of *Campylobacter* spp. in caeca and poultry carcasses.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

Table 1. Risk factors with an increased association with *Campylobacter* spp. colonization in broiler flocks along with the corresponding references.

RISK FACTOR	REFERENCES
Season (summer months)	Bouwknegt et al., 2004; Barrios et al., 2006; Huneau-Salaün et al., 2007; Zweifel et al., 2008; McDowell et al., 2008; Ellis-Iversen et al., 2009; Jore et al., 2010; EFSA, 2010b; Lawes et al., 2012; Chowdhury et al., 2012a
Age of broilers	Berndtson et al., 1996b; Evans & Sayers, 2000; Bouwknegt et al., 2004; Barrios et al., 2006; McDowell et al., 2008; EFSA, 2010b; Ansari- Lari et al., 2011; Chowdhury et al., 2012a; Lawes et al., 2012; Sommer et al., 2013
Partial depopulation practices	Hald et al., 2000; Hald et al., 2001; Slader et al., 2002; Ellis-Iversen et al., 2009; Hannson et al., 2010; EFSA, 2010b; Lawes et al., 2012
Lack of biosecurity measures	Humphrey et al., 1993; Van de Giessen et al. 1996; Gibbens et al., 2001; Herman et al., 2003; Cardinale et al., 2004
Flock size	Berndtson et al., 1996b; Barrios et al., 2006; Guerin et al., 2007a; Nather et al., 2009
Human traffic and farm equipment	Berndtson et al., 1996b; Evans & Sayers, 2000; Hald et al., 2000; Cardinale et al., 2004; Ramabu et al., 2004; Hofshagen & Kruse, 2005
Other animals on the farm or very close to the farm	van de Giessen et al., 1996; Bouwknegt et al., 2004; Cardinale et al., 2004; Lyngstad et al., 2008; Ellis-Iversen et al., 2009; Hannson et al., 2010; Sommer et al., 2013
General farm hygiene	Hald et al., 2000; Evans & Sayers, 2000; McDowell et al., 2008; Hannson et al., 2010
Type of drinking system	Näther et al., 2009
Contaminated water	Pearson et al., 1993; Zimmer et al., 2003
Contaminated air from adjacent poultry houses	Berndtson et al., 1996a
Mechanical transmission via insects	Berndtson et al., 1996a; Refregier-Petton et al., 2001
Infected wild birds	Chuma et al., 2000; Craven et al., 2000
Health and welfare status	Bull et al., 2008
Presence of rodents	Gregory et al., 1997; Huneau-Salaün et al., 2007; McDowell et al., 2008; Sommer et al., 2013
Free-range & organic flocks	Näther et al., 2009

Table 2. Risk factors with an increased association with broiler carcass contamination along with the corresponding references.

RISK FACTOR	REFERENCES
Slaughter in summer months	EFSA, 2010b; Powell et al., 2012
Age of broilers	EFSA, 2010b
Previous thinning of the flock	Hue et al., 2010
Batch was not slaughtered first in the slaughter program	Hue et al., 2010
Temperature in evisceration room (oC)	Hue et al., 2010
Presence of dirty marks on eviscerated carcasses	Hue et al., 2010
Time (hour) of sampling during day	EFSA, 2010b
Campylobacter-colonization in the broiler batch	Arsenault et al., 2007b; EFSA, 2010b
Batches with higher standard deviation of carcass weight	Mahler et al., 2011

REFERENCES

- Aboaba O.O & Smith SI (2005) Occurrence of *Campylobacter* species in poultry forms in Lagos area of Nigeria. *J Environ Biol* 26:403–408.
- Allen VM, Weaver H., Ridley AM, Harris JA, Sharma M, Emery J, Sparks N, Lewis M & Edge S (2008) Sources and spread of thermophilic *Campylobacter* spp. during partial depopulation of broiler chicken flocks. *J of Food Protect* 71:264–270.
- Allos BM (2001) *Campylobacter jejuni* Infections: update on emerging issues and trends. *Clin Infect Dis* 32:1201-6.
- Annan-Prah A, Janc M (1988) The mode of spread of *Campylobacter jejuni/coli* to broiler flocks. *J of Vet Medic* 35:11-18.
- Ansari-Lari M, Hosseinzadeh S, Shekarforoush SS, Abdollahi M & Berizi E (2011) Prevalence and risk factors associated with *Campylobacter* infections in broiler flocks in Shiraz, southern Iran. *Intern J of Food Microbiol* 144(3):475-479.
- Arsenault J, Letellier A, Quessy S, Normand V & Boulianne M (2007a) Prevalence and risk factors for *Salmonella* spp. and *Campylobacter* spp. caecal colonization in broiler chicken and turkey flocks slaughtered in Quebec, Canada. *Prev Vet Med* 81:250–264.
- Arsenault J, Letellier A, Quessy S & Boulianne M (2007b) Prevalence and risk factors for *Salmonella* and *Campylobacter* spp. carcass contamination in broiler chickens slaughtered in Quebec, Canada. *J Food Prot* 70:1820-1828.
- Atabay HI, Corry JE (1998) The isolation and prevalence of *Campylobacters* from dairy cattle using a variety of methods. *J Appl Microbiol* 84:733–740.
- Baker MG, Sneyd E, Wilson NA (2007) Is the major increase in notified campylobacteriosis in New Zealand real? *Epidem and Infect* 135:163-170.
- Barrios PR, Reiersen J, Lowman R, Bisailon JR, Michel P, Fridriksdóttir V, Gunnarsson E, Stern N, Berke O, McEwen S & Martin W (2006) Risk factors for *Campylobacter* spp. colonization in broiler flocks in Iceland. *Prev Vet Med* 74:264–278.
- Berndtson E, Danielsson-Tham ML & Engvall A (1996a) *Campylobacter* incidence on a chicken farm and the spread of *Campylobacter* during the slaughter process. *Int J Food Microbiol* 32:35-47.
- Berndtson E, Emanuelson U, Engvall A & Danielsson-Tham ML (1996b) A 1-year epidemiological study of *Campylobacter* in 18 Swedish chicken farms. *Prev Vet Med*, 26:167–185.
- Berrang ME, Buhr RJ, Cason JA, Dickens JA (2001) Broiler carcass contamination with *Campylobacter* from faeces during defeathering. *J Food Prot* 64:2063–2066.
- Black RE, Levine MM, Clements, ML, Hughes TP & Blaser MJ (1988) Experimental *Campylobacter jejuni* infection in humans. *The J of Infect Dis* 157:472-479.
- Blaser MJ, Engberg J (2008) Clinical aspects of *Campylobacter jejuni* and *Campylobacter coli* infections. In I. Nachamkin, C. M. Szymanski, M. J. Blaser (eds.), *Campylobacter*. ASM Press, Washington DC.
- Bouwknegt M, van de Giessen AW, Dam-Deisz WD, Havelaar AH, Nagelkerke NJ & Henken AM (2004) Risk factors for the presence of *Campylobacter* spp. in Dutch broiler flocks. *Prev Vet Med* 62:35–49.
- Boysen L & Rosenquist H (2009) Reduction of thermotolerant *Campylobacter* species on broiler carcasses following physical decontamination at slaughter. *J of Food Protect*, 72(3), 497-502.
- Bull SA, Allen VM, Domingue G, Jørgensen F, Frost JA, Ure R, Whyte R, Tinker D, Corry JE, Gillard-King J. & Humphrey TJ (2006) Sources of *Campylobacter* spp. colonizing housed broiler flocks during rearing. *Appl and Environ Microbiol* 72:645–652.
- Bull SA, Thomas AO, Humphrey TJ, Ellis-Iversen J, Cook AJ, Lovell RDL & Jørgensen F. (2008). Flock health indicators and *Campylobacter* spp. in commercial housed broilers reared in Great Britain. *Appl and Environ Microbiol* 74:5408–5413.
- Callicott KA, Friethriksdóttir V, Reiersen J, Lowman R, Bisailon JR, Gunnarsson E, Berndtson E, Hielt KL, Needleman DS & Stern NJ (2006) Lack of evidence for vertical transmission of *Campylobacter* spp. in chickens. *Appl and Environ Microbiol* 72:5794-5798.
- Cardinale E, Tall F, Gueye EF, Cisse M & Salvat G (2004) Risk factors for *Campylobacter* spp. infection in Senegalese broiler-chicken flocks. *Prev Vet Med* 64:15–25.
- Council for Agricultural Science and Technology, CAST (1994) Foodborne Pathogens: Risk and Consequences. Task Force Report No. 122. Iowa State University, Ames, IA.
- CDC (2013) Centers for Disease Control and Prevention. Incidence and Trends of Infection with Pathogens Transmitted Commonly Through Food — Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 1996–2012. *MMWR* 2013;62:283-287
- CDC (2013) Foodborne outbreak online database (FOOD). Atlanta, GA: US Department of Health and Human Services, CDC; 1998–2011.
- Chantarapanont W, Berrang M, Frank JF (2003) Direct microscopic observation and viability determination of *Campylobacter jejuni* on chicken skin. *J Food Prot* 66:2222–2230.
- Chatzipanagiotou S, Papavasileiou E, Lakumenta A, Makri A, Nicolaou C, Chantzis K, Manganas S & Legakis NI (2002) Antimicrobial susceptibility patterns of *Campylobacter jejuni* strains isolated from hospitalized children in Athens, Greece. *J Antimicrob Chemother* 49(5):803-5.
- Chatzipanagiotou S, Papavasileiou E, Lakumenta A, Makri A, Nicolaou C, Chantzis K, Manganas S & Legakis NI (2003a) Heat-stable antigen serotyping of *Campylobacter jejuni* strains isolated from hospitalized children in Athens, Greece. *Eur J Epidemiol* 18(11):1097-100.
- Chatzipanagiotou S, Kilidireas K, Trimis G, Nicolaou C, Anagnostouli M, Athanassaki C, Giannoulia A, Legakis N & Youroukos S (2003b) *Campylobacter jejuni* O:19 serotype-associated Guillain-Barré syndrome in a child: the first case reported from Greece. *Clin Microbiol Infect* 9(1):69-72.
- Chokboonmongkol C, Patchanee P, Gözl G, Zessin KH & Alter T (2013) Prevalence, quantitative load, and antimicrobial resistance of *Campylobacter* spp. from broiler ceca and broiler skin samples in Thailand. *Poult Sci* 92:462–467.
- Chowdhury S, Sandberg M, Themudo GE & Ersbøll AK (2012) Risk factors for *Campylobacter* infection in Danish broiler chickens. *Poultry Sci* 91:2701-2709.
- Chuma T, Hashimoto S & Okamoto K (2000) Detection of thermophilic *Campylobacter* from sparrows by multiplex PCR: the role of sparrows as a source of contamination of broilers with

- Campylobacter*. J. Vet. Med. Sci. 62, 1291-1295.
- Coker A, Isokpehi R, Thomas B, Amisu K, & Obi C (2002) Human campylobacteriosis in developing countries. *Emerg Infect Dis* 8(3):237-243
- Corry JEL, Atabay HI (2001) Poultry as a source of *Campylobacter* and related organisms. *J Appl Microbiol* 90:96S-114S.
- Cox NA, Richardson LJ, Maurer JJ, Berrang ME, Fedorka-Cray PJ, Buhr RJ, Byrd JA, Lee MD, Hofarce CL, O’Cane PM, Lammerding AM, Clark AG, Thayer SG, Doyle MP (2012) Evidence for horizontal and vertical transmission in *Campylobacter* passage from hen to her progeny. *J Food Prot.* 75(10):1896-1902.
- Craven SE, Stern NJ, Line E, Bailey JS, Cox NA & Fedorka-Cray P (2000) Determination of the incidence of *Salmonella* spp, *Campylobacter jejuni*, and *Clostridium perfringens* in wild birds near broiler chicken houses by sampling intestinal droppings. *Avian Dis.* 44, 715-720.
- De Boer P, Wagenaar JA, Achterberg RP, van Putten JPM, Schouls LM & Duim B (2002) Generation of *Campylobacter jejuni* genetic diversity *in vivo*. *Molecular Microbiol* 44(2):351-359.
- Doorduyn Y, van den Brandhof WE, van Duynhoven YT, Breukink BJ, Wagenaar JA & Van Pelt W (2010) Risk factors for indigenous *Campylobacter jejuni* and *Campylobacter coli* infections in The Netherlands: a case-control study. *Epidem and Infect* 138:1391-1404.
- Eberhart-Phillips J, Walker N, Garrett N, Bell D, Sinclair D, Rainger W, Bates M (1997) Campylobacteriosis in New Zealand: results of a case-control study. *J Epidemiol Commun Health* 51:686-691.
- EFSA (2006) The Community Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents, Antimicrobial Resistance and Foodborne Outbreaks in the European Union in 2005, *The EFSA Journal* (2006), 94
- EFSA (2010a) Analysis of the baseline survey on the prevalence of *Campylobacter* in broiler batches and of *Campylobacter* and *Salmonella* on broiler carcasses in the EU, 2008, Part A: *Campylobacter* and *Salmonella* prevalence estimates. *EFSA Journal* 2010; 8(03):1503. [100 pp.].
- EFSA (2010b) Analysis of the baseline survey on the prevalence of *Campylobacter* in broiler batches and of *Campylobacter* and *Salmonella* on broiler carcasses, in the EU, 2008; Part B: Analysis of factors associated with *Campylobacter* colonization of broiler batches and with *Campylobacter* contamination of broiler carcasses; and investigation of the culture method diagnostic characteristics used to analyse broiler carcass samples. *EFSA Journal* 2010; 8(8):1522. [132 pp.].
- EFSA (2010c) EFSA Panel on Biological Hazards (BIOHAZ); Scientific Opinion on Quantification of the risk posed by broiler meat to human campylobacteriosis in the EU. *EFSA Journal* 2010; 8(1):1437. [89 pp.].
- EFSA (2011) EFSA Panel on Biological Hazards (BIOHAZ); Scientific Opinion on *Campylobacter* in broiler meat production: control options and performance objectives and/or targets at different stages of the food chain. *EFSA Journal* 2011;9(4):2105. [141 pp.].
- EFSA (2013a) EFSA, (European Food Safety Authority), ECDC (European Centre for Disease Prevention and Control), 2013. The European Union Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and Food-borne Outbreaks in 2011; *EFSA Journal* 2013;11(4):3129, 250 pp.
- EFSA (2013b) EFSA (European Food Safety Authority) and ECDC (European Centre for Disease Prevention and Control), 2013. The European Union Summary Report on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food in 2011. *EFSA Journal* 2013;11(5):3196, 359 pp.
- EFSA (2014) EFSA (European Food Safety Authority) and ECDC (European Centre for Disease Prevention and Control), 2014. The European Union Summary Report on Trends and Sources of Zoonoses, Zoonotic Agents and Food-borne Outbreaks in 2012. *EFSA Journal* 2014;12(2):3547, 312 pp.
- Ekdahl K, Andersson Y (2004) Regional risks and seasonality in travel associated Campylobacteriosis. *BMC Infect Dis* 4(1):54.
- Ellis-Iversen J, Jorgensen F, Bull S, Powell L, Cook AJ & Humphrey TJ (2009) Risk factors for *Campylobacter* colonisation during rearing of broiler flocks in Great Britain. *Prev Vet Med* 89:178-184.
- El-Shibiny A, Connerton PL & Connerton IF (2005) Enumeration and diversity of *campylobacters* and bacteriophages isolated during the rearing cycles of free-range and organic chickens. *Appl and Environ Microbiol* 71 (3):1259-1266.
- Evans SJ & Sayers AR (2000) A longitudinal study of *Campylobacter* infection of broiler flocks in Great Britain. *Prev Vet Med* 46:209-223.
- Food Safety Authority of Ireland: Control of *Campylobacter* species in food chain, 2002, ISBN I-904465-00-5
- Fussing V, Moller NE, Neimann J, Engberg J (2007) Systematic serotyping and ribotyping of *Campylobacter* spp. improves surveillance: experiences from two Danish counties. *Clin Microbiol and Infect* 13:635-642.
- Gibbins JC, Pascoe SJ, Evans SJ, Davies RH & Sayers AR (2001) A trial of biosecurity as a means to control *Campylobacter* infection of broiler chickens. *Prev Vet Med* 48:85-99.
- Gillespie IA, O’Brien SJ, Adak GK, Tam CC, Frost JA, Bolton FJ, Tompkins DS & *Campylobacter* Sentinel Surveillance Scheme Collaborators (2003) Point source outbreaks of *Campylobacter jejuni* infection—are they more common than we think and what might cause them? *Epidem and Infect* 130:367-375.
- Gradel KO, Schonheyder HC, Dethlefsen C, Kristensen B, Ejlersen T & Nielsen H (2008) Morbidity and mortality of elderly patients with zoonotic *Salmonella* and *Campylobacter*: a population-based study. *J of Infect* 57:214-222.
- Gradel KO, Nielsen HL, Schonheyder HC, Ejlersen T, Kristensen B & Nielsen H (2009) Increased short- and long-term risk of inflammatory bowel disease after *Salmonella* or *Campylobacter* gastroenteritis. *Gastroenterol* 137:495-501.
- Gregory E, Bamhart H, Dreesen DW, Stern NJ & Corn JL (1997) Epidemiological study of *Campylobacter* spp in broilers: source, time of colonization, and prevalence. *Avian Dis* 41:890-898.
- Guerin MT, Martin SW, Reiersen J, Berke O, McEwen SA, Fridriksdóttir V, Bisailon JR, Lowman R, Campy-on-Ice Consortium. (2008) Temperature-related risk factors associated with the colonization of broiler-chicken flocks with *Campylobacter* spp. in Iceland, 2001-2004. *Prev Vet Med* 86:14-29.
- Guerin MT, Martin W, Reiersen J, Berke O, McEwen SA, Bisailon JR & Lowman R (2007a) A farm-level study of risk factors associated with the colonization of broiler flocks with *Campylobacter* spp. in Iceland, 2001-2004. *Acta Vet Scand* 49:18.

- Guerin MT, Martin W, Reiersen J, Berke O, McEwen SA, Bisailon JR & Lowman R (2007b) House-level risk factors associated with the colonization of broiler flocks with *Campylobacter* spp. in Iceland, 2001-2004. *BMC Vet Res* 12:3-30.
- Haagsma JA, Siersema PD, de Wit NJ, Havelaar AH (2010) Disease burden of post-infectious irritable bowel syndrome in The Netherlands. *Epidemiol Infect* 138: 1650-1656.
- Habib I, Sampers I, Uyttendaele M, Berkvens D & De Zutter L (2008) Baseline data from a Belgium-wide survey of *Campylobacter* species contamination in chicken meat preparations and considerations for a reliable monitoring program. *Appl and Environ Microbiol* 74:5483-5489.
- Hald B, Rattenborg E & Madsen M (2001) Role of batch depletion of broiler houses on the occurrence of *Campylobacter* spp. in chicken flocks. *Letters in Appl Microbiol* 32:253-256.
- Hald B, Skovgard H, Bang DD, Pedersen K, Dybdahl J, Jespersen JB & Madsen M (2004) Flies and *Campylobacter* infection of broiler flocks. *Emerg Infect Dis* 10:1490-1492.
- Hald B, Skovgard H, Pedersen K & Bunkenborg H (2008) Influxed insects as vectors for *Campylobacter jejuni* and *Campylobacter coli* in Danish broiler houses. *Poultry Sci* 87:1428-1434.
- Hald B, Wedderkopp A & Madsen M (2000) Thermophilic *Campylobacter* spp. in Danish broiler production: a cross-sectional survey and a retrospective analysis of risk factors for occurrence in broiler flocks. *Avian Pathol* 29:123-131.
- Hansson I, Pudas N, Harbom B & Engvall EO (2010) Within-flock variations of *Campylobacter* loads in caeca and on carcasses from broilers. *Intern J of Food Microbiol* 141:51-55.
- Hansson, I., Vagsholm, I., Svensson, L. & Olsson Engvall, E.. (2007). Correlations between *Campylobacter* spp. prevalence in the environment and broiler flocks. *J of Appl Microbiol* 103:640-649.
- Havelaar AH, Nauta MJ, Mangen M JJ, de Koeijer AG, Bogaardt MJ, Evers EG, Jacobs-Reitsma WF, van Pelt W, Wagenaar JA, de Wit GA, van der Zee H (2005) Costs and Benefits of Controlling *Campylobacter* in the Netherlands; Integrating Risk Analysis, Epidemiology and Economics. RIVM report 250911009/2005.
- Hellenic Center for Disease Control & Protection, HCDCP (2013) Laboratory capability of *Campylobacter* isolation in Greek hospitals and number of positive cultures in 2012. Available at: <http://www.keelpno.gr/Portals/0/Αρχεία/Τροφιμογενή/Καμπυλοβακτηρίδιο/Εργαστηριακή%20Δυνατότητα%20%202012-%20Campylobacter.pdf>
- Helms M, Vastrup P, Gerner-Smidt P & Molbak K (2003) Short and long term mortality associated with foodborne bacterial gastrointestinal infections: Registry based study. *BMJ* 326(7356):357.
- Henry I, Reichardt J, Denis M & Cardinale E (2011) Prevalence and risk factors for *Campylobacter* spp. in chicken broiler flocks in Reunion Island (Indian Ocean). *Prev Vet Med*, 10:64-70.
- Herman L, Heyndrickx M, Grijspeerdt K, Vandekerchove D, Rollier I & De Zutter L (2003) Routes for *Campylobacter* contamination of poultry meat: epidemiological study from hatchery to slaughterhouse. *Epidem and Infect* 131:1169-1180.
- Hofshagen M & Kruse H (2005) Reduction in flock prevalence of *Campylobacter* spp. in broilers in Norway after implementation of an action plan. *J of Food Protect* 68:2220-2223.
- Hook H, Fattah M, Ericsson H, Vagsholm I & Danielsson-Tham M (2005) Genotype dynamics of *Campylobacter jejuni* in a broiler flock. *Vet Microbiol* 106:109-117.
- Hue O, Le Bouquin S, Laisney MJ, Allain V, Lalande F, Petetin I, Rouxel S, Quesne S, Gloaguen PY, Picherot M, Santolini J, Salvat G, Bougeard S & Chemaly M (2010) Prevalence of and risk factors for *Campylobacter* spp. contamination of broiler chicken carcasses at the slaughterhouse. *Food Microbiol* 27:992-999.
- Hue O, Allain V, Laisney MJ, Le Bouquin S, Lalande F, Petetin I, Rouxel S, Quesne S, Gloaguen PY, Picherot M, Santolini J, Bougeard S, Salvat G & Chemaly M (2011) *Campylobacter* contamination of broiler caeca and carcasses at the slaughterhouse and correlation with *Salmonella* contamination. *Food Microbiol* 28:862-868
- Humphrey TJ, Henley A & Lanning DG (1993) The colonization of broiler chickens with *Campylobacter jejuni*: some epidemiological investigations. *Epidemiol Infect* 110:601-607.
- Huneau-Salaün A, Denis M, Balaine L & Salvat G (2007) Risk factors for *Campylobacter* spp. colonization in French free-range broiler-chicken flocks at the end of the indoor rearing period. *Prev Vet Med* 80:34-48.
- Ioannidis A, Nicolaou C & Chatzipanagiotou S (2009) Correlation between flagellin A (flaA) genotypes and antimicrobial susceptibility patterns of *Campylobacter jejuni* strains isolated from children with gastroenteritis in Athens, Greece. *Mol Diagn Ther* 13(6):389-95.
- Ioannidis A, Nicolaou C, Legakis NJ, Ioannidou V, Papavasileiou E, Voyatzis A & Chatzipanagiotou S (2006) Genotyping of human *Campylobacter jejuni* isolates in Greece by pulsed-field gel electrophoresis. *Mol Diagn Ther* 10(6):391-6.
- Ioannidou V, Ioannidis A, Magiorkinis E, Bagos P, Nicolaou C, Legakis N & Chatzipanagiotou S (2013) Multilocus sequence typing (and phylogenetic analysis) of *Campylobacter jejuni* and *Campylobacter coli* strains isolated from clinical cases in Greece. *BMC Res Notes* 6:359.
- Isohanni P (2013) Survival and destruction of strains of *Campylobacter* species in broiler meat. PhD Thesis, University of Helsinki, Finland <http://www.helsinki.fi/ruralia/julkaisut/pdf/publications30.pdf>
- Jacobs-Reitsma W, Lyhs U & Wagenaar J (2008) *Campylobacter* in the food supply, in *Campylobacter* Third edn., ed. Nachamkin, I., Szymanski, C.M. & Blaser, M.J. *ASM Press, Washington, DC*. pp. 627-644.
- Jacobs-Reitsma WF, van de Giessen AW, Bolder NM & Mulder RW (1995) Epidemiology of *Campylobacter* spp. at two Dutch broiler farms. *Epidem and Infect* 114(3):413-421.
- Jakopanec I, Borgen K, Vold L, Lund H, Forseth T, Hannula R, Nygard K (2008) A large waterborne outbreak of campylobacteriosis in Norway: The need to focus on distribution system safety. *BMC Infectious Diseases* 8:128.
- Johannessen GS, Johnsen G, Okland M, Cudjoe KS & Hofshagen M (2007) Enumeration of thermotolerant *Campylobacter* spp. from poultry carcasses at the end of the slaughter-line. *Letts in Appl Microbiol* 44:92-97.
- Johnsen G, Kruse H & Hofshagen M (2006) Genetic diversity and description of transmission routes for *Campylobacter* on broiler farms by amplified-fragment length polymorphism. *J of Appl Microbiol* 101:1130-1139.
- Jone DR & Musgrove MT (2007) Pathogen prevalence and microbial levels associated with restricted shell eggs. *J Food Prot*. 70(9):2004-2007.
- Jore S, Viljugrein H, Brun E, Heier BT, Borck B, Ethelberg S,

- Hakkinen M, Kuusi M, Reiersen J, Hansson I, Engvall EO, Løfdahl M, Wagenaar JA, van Pelt W & Hofshagen M (2010) Trends in *Campylobacter* incidence in broilers and humans in six European countries, 1997-2007. *Prev Vet Med* 93:33-41.
- Jørgensen F, Bailey R, Williams S, Henderson P, Wareing DRA, Bolton FJ, Frost JA, Ward L & Humphrey TJ (2002) Prevalence and numbers of *Salmonella* and *Campylobacter* spp. on raw, whole chickens in relation to sampling methods. *Intern J of Food Microbiol* 76:151-164.
- Jørgensen F, Ellis-Iversen J, Rushton S, Bull S, Harris SA, Bryan SJ, Gonzalez A & Humphrey TJ (2011) Influence of season and geography on *Campylobacter jejuni* and *C. coli* subtypes in housed broiler flocks reared in Great Britain. *Appl and Environ Microbiol* 77:3741-3748.
- Kafetzis DA, Maltezos HC, Zafeiropoulou A, Attilakos A, Stavriniadis C & Foustoukou M (2001) Epidemiology, clinical course and impact on hospitalization costs of acute diarrhoea among hospitalized children in Athens, Greece. *Scand J Infect Dis* 33(9):681-5.
- Kapperud G, Espeland G, Wahl E, Walde A, Herikstad H, Gustavsen S, Tveit I, Natås O, Bevanger L & Digranes A (2003) Factors associated with increased and decreased risk of *Campylobacter* infection: a prospective case-control study in Norway. *American J of Epidemiol* 158:234-242.
- Karagiannis I, Sideroglou T, Gkolfinopoulou K, Tsouri A, Lampousaki D, Velonakis E, Scoulika E, Mellou K, Panagiotopoulos T & Bonovas S (2010a) A waterborne *Campylobacter jejuni* outbreak on a Greek island. *Epidemiol. Infect.*, 138(12):1726-34
- Karagiannis I, Sideroglou T, Gkolfinopoulou K, Velonakis E, Scoulika E, Panagiotopoulos T, Mellou K & Bonovas S (2010b) A *Campylobacter jejuni* outbreak investigation in Crete, Greece: indication for waterborne spread. *ECCMID 10-13 April 2010, Vienna, Austria*
- Kendall ME, Crim S, Fullerton K, Han PV, Cronquist AB, Shiferaw B, Ingram LA, Rounds J, Mintz ED, Mahon BE (2012) Travel-associated enteric infections diagnosed after return to the United States, Foodborne Diseases Active Surveillance Network (FoodNet), 2004-2009. *Clin Infect Dis* 54 Suppl 5:S480-7.
- Kuana SL, Santos LR, Rodrigues LB, Borsoi A, Moraes HL, Salle CT & Nascimento VP (2008) Occurrence and characterization of *Campylobacter* in the Brazilian production and processing of broilers. *Avian Dis* 52:680-684.
- Lastovica A & Allos BM (2008) Clinical significance of *Campylobacter* and related species other than *Campylobacter jejuni* and *Campylobacter coli*. In: *Campylobacter*, Nachamkin, I, Szymanski, C, Blaser, M (eds.) ASM Press, Washington, DC, USA.
- Lawes JR, Vidal A, Clifton-Hadley FA, Sayers R, Rodgers J, Snow L, Evans SJ & Powell LF (2012) Investigation of prevalence and risk factors for *Campylobacter* in broiler flocks at slaughter: results from a UK survey. *Epidem and Infect* 140(10):1725-1737.
- Lee A, Smith SC, Coloe PJ (1998) Survival and growth of *Campylobacter jejuni* after artificial inoculation onto chicken skin as a function of temperature and packaging conditions. *J Food Prot* 61:1609-1614.
- Lee MD & Newell DG (2006) *Campylobacter* in poultry: filling an ecological niche. *Avian Dis* 50:1-9.
- Little CL, Gormley FJ, Rawal N & Richardson J (2010) A recipe for disaster: Outbreaks of campylobacteriosis associated with poultry liver pâté in England and Wales. *Epidemiol Infect* 138:1691-1694.
- Lyngstad TM, Jonsson ME, Hofshagen M & Heier BT (2008) Risk factors associated with the presence of *Campylobacter* species in Norwegian broiler flocks. *Poultry Sci*, 87, 1987-1994.
- Malher X, Simon M, Charnay V, Déserts RD, Lehébel A & Belloc C (2011) Factors associated with carcass contamination by *Campylobacter* at slaughterhouse in cecal-carrier broilers. *Int J Food Microbiology* 150:8-13.
- Maltezos HC, Zafiropoulou A, Mavrikou M, Bozavoutoglou E, Liapi G, Foustoukou M & Kafetzis DA (2001) Acute diarrhoea in children treated in an outpatient setting in Athens, Greece. *J Infect* 43(2):122-127.
- Mammas IN, Koutsaftiki C, Nika E, Vagia F, Voyatzi A, Spandidos DA, Theodoridou M & Myriokefalitakis N (2012) Prospective study of human norovirus infection in children with acute gastroenteritis in Greece. *Minerva Pediatr* 64(3):333-9.
- Mangen MJJ, Havelaar AH, Bernsen RAJAM, Koningsveld RV & Wit GAD (2005) The costs of human *Campylobacter* infections and sequelae in the Netherlands: A DALY and cost-of-illness approach. *Acta Agricultura Scandinavica. Section C, Food Economics* 2:35-51.
- Maragkoudakis S, Poulidaki SR, Papadomanolaki E, Alevraki G, Papadogianni M, Oikonomou N & Fanourgiakis P (2010) Empiric antimicrobial therapy and infectious diarrhoea. Do we need local guidelines? *Eur J Intern Med* 22(5):e60-62.
- Maraki S, Ladomenou F, Samonis G & Galanakis E (2012) Long-term trends in the epidemiology and resistance of childhood bacterial enteropathogens in Crete. *Eur J Clin Microbiol Infect Dis* 31(8):1889-1894.
- Maraki S, Georgiladakis A, Tselentis Y & Samonis G (2003) A 5-year study of the bacterial pathogens associated with acute diarrhoea on the island of Crete, Greece, and their resistance to antibiotics. *Eur J Epidemiol* 18(1):85-90
- Marinou I, Bersimis S, Ioannidis A, Nicolaou C, Mitroussia-Ziouva A, Legakis NJ & Chatzipanagiotou S (2013) Identification and antimicrobial resistance of *Campylobacter* species isolated from animal sources. *Frontiers in Microbiol*, Volume3, Article58.
- Martin S, Penttinen P, Hedin G, Ljungstrom M, Allestam G, Anderson Y et al. (2006) A case-cohort study to investigate concomitant waterborne outbreaks of *Campylobacter* and gastroenteritis in Soderhamn, Sweden, 2002-3. *Journal Water Health* 4(4):417-424.
- Maziero MT, de Oliveira TCRM (2010) Effect of refrigeration and frozen storage on the *Campylobacter jejuni* recovery from naturally contaminated broiler carcasses. *Braz J Microbiol* 42(2):501-505.
- McDowell SW, Menzies FD, McBride SH, Oza AN, McKenna JP, Gordon AW & Neill SD (2008) *Campylobacter* spp. in conventional broiler flocks in Northern Ireland: epidemiology and risk factors. *Prev Vet Med* 84:261-276.
- McGrogan A, Madle GC, Seaman HE, de Vries CS (2009) The epidemiology of Guillain-Barré syndrome worldwide. A systematic literature review. *Neuroepidemiol* 32(2):150-63.
- Meeyam T, Padungtod P & Kaneene JB (2004) Molecular characterization of *Campylobacter* isolated from chickens and humans in northern Thailand. *Southeast Asian J of Tropical Med and Public Health* 35:670-675.

- Mellou K, Sourtzi P, Tsakris A, Saroglou G & Velonakis E (2010) Risk factors for sporadic *Campylobacter jejuni* infections in children in a Greek region. *Epidemiol Infect* 138(12):1719-25.
- Messelh usser U, Th arigen D, Elmer-Englhard D, Bauer H, Schreiner H, H oller C (2011) Occurrence of thermotolerant *Campylobacter* spp. on eggshells: a missing link for food-borne infections? *Appl Environ Microbiol*. 77(11):3896-3897.
- Miller G, Dunn GM, Smith-Palmer A, Ogden ID & Strachan NJ (2004) Human campylobacteriosis in Scotland: seasonality, regional trends and bursts of infection. *Epidemiol and Infect* 132:585-593
- Moore JE, Corcoran D, Dooley JS, Fanning S, Lucey B, Matsuda M, McDowell DA, Megraud F, Millar BC, O'Mahony R, O'Riordan L, O'Rourke M, Rao JR, Rooney PJ, Sails A & Whyte P (2005) *Campylobacter*. *Vet Research* 36:351- 382.
- Nadeau E, Messier S, Quessy S (2002) Prevalence and comparison of genetic profiles of *Campylobacter* strains isolated from poultry and sporadic cases of campylobacteriosis in humans. *J Food Prot* 65:73-78.
- N ather G, Alter T, Martin A & Ellerbroek L (2009) Analysis of risk factors for *Campylobacter* species infection in broiler flocks. *Poultry Sci* 88:1299-1305.
- Neimann J, Engberg J, Molbak K & Wegener HC (2003) A case-control study of risk factors for sporadic *Campylobacter* infections in Denmark. *Epidemiol and Infect* 130:353-366.
- Nesbakken T, Eckner K, Hoidal HK, Rotterud O (2003) Occurrence of *Yersinia enterocolitica* and *Campylobacter* spp. in slaughter pigs and consequences for meat inspection, slaughtering and dressing procedures. *Int J Food Microbiol* 80:231-240.
- Nielsen EM, Fussing V, Engberg J, Nielsen NL & Neimann J (2006) Most *Campylobacter* subtypes from sporadic infections can be found in retail poultry products and food animals. *Epidem and Infect* 13:758-767.
- Nygaard K, Andersson Y, Rottingen JA, Svensson A, Lindback J, Kistemann T, Giesecke J (2004) Association between environmental risk factors and *Campylobacter* infections in Sweden. *Epidemiol Infect* 132:317-325.
- Nylen G, Dunstan F, Palmer SR, Andersson Y, Bager F, Cowden J, Feierl G, Galloway Y, Kapperud G, M egraud F, Molbak K, Petersen LR & Ruutu P (2002) The seasonal distribution of campylobacter infection in nine European countries and New Zealand. *Epidemiol and Infect* 128(3):383-390.
- Oberhelman RA & Taylor DN (2000) *Campylobacter* infections in developing countries. In (eds. Nachamkin I, Blaser MJ) *Campylobacter*, 2nd edn. Washington: American Soc for Microbiol, p.139-53.
- O'Leary MC, Harding O, Fisher L & Cowden J (2009) A continuous common-source outbreak of campylobacteriosis associated with changes to the preparation of chicken liver p ate. *Epidemiol Infect* 137:383-388.
- Olson CK, Ethelberg, S, van Pelt W & Tauxe RV (2008) Epidemiology of *Campylobacter jejuni* infections in industrialized nations. In: Nachamkin I, Szymanski CM & Blaser) *Campylobacter*, 3rd edn., M.J. ASM Press, Washington, DC. pp. 163-189.
- Orr KE, Lighfoot NF, Sisson PR, Harkis BA, Tveddle JL, Boyd P, Carroll A, Jackson CJ, Wareing DRA, Freeman R (1995) Direct milk excretion of *Campylobacter jejuni* in a dairy cow causing cases of human enteritis. *Epidemiol Infect* 114:15-24.
- Padungtod P & Kaneene JB (2005) *Campylobacter* in food animals and humans in northern Thailand. *J of Food Protect* 68:2519-2526.
- Papavasileiou E, Voyatzi A, Papavasileiou K, Makri A, Andrianopoulou I & Chatzipanagiotou S (2007) Antimicrobial susceptibilities of *Campylobacter jejuni* isolates from hospitalized children in Athens, Greece, collected during 2004-2005. *Eur J Epidemiol* 22(1):77-8.
- Parry A, Fearnley E & Denehy, E (2012) 'Surprise': outbreak of *Campylobacter* infection associated with chicken liver p ate at a surprise birthday party, Adelaide, Australia, 2012. *Western Pac Surveill Response J* 3:16-9.
- Patrick M (2007) Emerging infections program. FoodNet News Vol. 1 (1). Available at: http://cdc.gov/foodnet/news/2007/October2007_foodnet_news.pdf.
- Patrick ME, Christiansen LE, Waino M, Ethelberg S, Madsen H & Wegener HC (2004) Effects of climate on incidence of *Campylobacter* spp. in humans and prevalence in broiler flocks in Denmark. *Appl and Environm Microbiol* 70:7474-7480.
- Pearson AD, Greenwood M, Healing TD, Rollins D, Shahamat M, Donaldson J & Colwell RR (1993) Colonization of broiler chickens by waterborne *Campylobacter jejuni*. *Appl and Environm Microbiol* 59:987-996.
- Perko-M akel a P, Isohanni P, Katzav M, Lund M, H anninen ML & Lyhs U (2009) A longitudinal study of *Campylobacter* distribution in a turkey production chain. *Acta Vet Scandinav* 51:18-28.
- Petersen L & Wedderkopp A (2001) Evidence that certain clones of *Campylobacter jejuni* persist during successive broiler flock rotations. *Appl Environ Microbiol* 67:2739-2745.
- Petridou E, Zdragas A (2009) Investigation upon the presence of *Campylobacter* spp. in poultry meat and their antimicrobial resistance in Northern Greece. Poster in XVI WVPA Congress: P98 (Marrakesh, Morocco).
- Peyrat MB, Soumet C, Maris P & Sanders P (2008) Recovery of *Campylobacter jejuni* from surfaces of poultry slaughterhouses after cleaning and disinfection procedures: analysis of a potential source of carcass contamination. *Intern J of Food Microbiol* 124:188-194.
- Powell LF, Lawes JR, Clifton-Hadley FA, Rodgers J, Harris K, Evans SJ & Vidal A (2012) The prevalence of *Campylobacter* spp. in broiler flocks and on broiler carcasses, and the risks associated with highly contaminated carcasses. *Epidemiol Infect* 140(12):2233-2246.
- Ramabu SS, Boxall NS, Madie P & Fenwick SG (2004) Some potential sources for transmission of *Campylobacter jejuni* to broiler chickens. *Letters in Appl Microbiol* 39:252-256.
- Rasschaert G, Houf K, Van Hende J & De Zutter L (2007) Investigation of the concurrent colonization with *Campylobacter* and *Salmonella* in poultry flocks and assessment of the sampling site for status determination at slaughter. *Vet Microbiol* 123:104-109.
- Refregier-Petton J, Rose N, Denis M & Salvat G (2001) Risk factors for *Campylobacter* spp. contamination in French broiler-chicken flocks at the end of the rearing period. *Prev Vet Med*, 50:89-100.
- Reich F, Atanassova V, Haunhorst E & Klein G (2008) The effects of *Campylobacter* numbers in caeca on the contamination of broiler carcasses with *Campylobacter*. *Intern J of Food Microbiol* 127:116-120.
- Rivoal K, Denis M, Salvat G, Colin P & Ermel G (1999) Molecular characterization of the diversity of *Campylobacter* spp. isolates collected from a poultry slaughterhouse: analysis of cross-con-

- tamination. *Letters in Appl Microbiol* 29:370–374.
- Rosenquist H, Sommer HM, Nielsen NL & Christensen BB (2006) The effect of slaughter operations on the contamination of chicken carcasses with thermotolerant *Campylobacter*. *Intern J of Food Microbiol* 108:226-232.
- Rushton SP, Humbhrey TJ, Shirley MD, Bull S & Jorgensen F (2009) *Campylobacter* in housed broiler chickens: A longitudinal study of risk factors. *Epidemiol and Infect* 86:14-29.
- Saeed AM, Harris NV, DiGiacomo RF (1993) The role of exposure to animals in the aetiology of *Campylobacter jejuni/coli* enteritis. *Am J Epidemiol* 137:108–114
- Sahin O, Kobalka P & Zhang Q (2003) Detection and survival of *Campylobacter* in chicken eggs. *J Appl Microbiol* 95:1070-1079.
- Sampers I, Habib I, Berkvens D, Dumoulin A, De Zutter L & Uyttendaele M (2008) Processing practices contributing to *Campylobacter* contamination in Belgian chicken meat preparations. *Intern J of Food Microbiol* 128:97–303.
- Samuel MC, Vugia DJ, Shallow S, Marcus R, Segler S, McGivern T, Kassenborg H, Reilly K, Kennedy M, Angulo F & Tauxe RV (2004) Epidemiology of sporadic *Campylobacter* infection in the United States and declining trend in incidence, FoodNet 1996-1999. *Clinic Infect Dis* 38:S165-174.
- Sasaki Y, Tsujiyama Y, Tanaka H, Yoshida S, Goshima T, Oshima K, Katayama S, Yamada Y (2011) Risk factors for *Campylobacter* colonization in broiler flocks in Japan. *Zoonoses Public Health* 58(5):350-356.
- Sato M & Sashihara N (2010) Occurrence of *Campylobacter* in commercially broken liquid egg in Japan. *J Food Prot.* 73(3):412-417.
- Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson M, Roy SL, Jones JL & Griffin PM (2011) Foodborne illness acquired in the United States—major pathogens. *Emerg Infect Dis* 17:7–15.
- Scherer K, Bartelta E, Sommerfelda C, Hildebrandt G (2006) Comparison of different sampling techniques and enumeration methods for the isolation and quantification of *Campylobacter* spp. in raw retail chicken legs. *Int J Food Microbiol* 108:115–119.
- Schorr D, Schmid H, Rieder HL, Baumgartner A, Vorlauf H, Burnens A (1994) Risk factors for *Campylobacter enteritis* in Switzerland. *Zentralbl Hyg Umweltmed* 196:327–337.
- Sejvar JJ, Baughman AL, Wise M, Morgan OW. (2011) Population incidence of Guillain-Barré syndrome: a systematic review and meta-analysis. *Neuroepidemiol.* 36(2):123-33.
- Silva J, Leite D, Fernandes M, Mena C, Gibbs PA, Teixeira P (2011) *Campylobacter* spp. as a foodborne pathogen: a review. *Front in Microbiol* 200(2):1-12
- Skirrow MB (1998) “*Campylobacteriosis*,” in *Zoonoses*, eds Palmer S. R., Lord Soulsby S. R., Simpson D. I. H., editors. (New York: Oxford University Press), 37–46.
- Slader J, Domingue G, Jorgensen F, McAlpine K, Owen RJ, Bolton FJ & Humphrey TJ (2002) Impact of transport crate reuse and of catching and processing on *Campylobacter* and *Salmonella* contamination of broiler chickens. *Appl and Environm Microbiol* 68:713–719.
- Smith JL & Bayles D (2007) Postinfectious irritable bowel syndrome: A long-term consequence of bacterial gastroenteritis. *J Food Prot* 70:1762-9.
- Sommer HM, Heuer OE, Sørensen AI & Madsen M (2013) Analysis of factors important for the occurrence of *Campylobacter* in Danish broiler flocks. *Prev Vet Med*, 111:100-111.
- Stafford RJ (2010) A Study of the Epidemiology of Sporadic *Campylobacter* Infection in Australia. PhD Thesis, School of Population Health, The University of Queensland.
- Stafford RJ, Schluter P, Kirk M, Wilson A, Unicomb L, Ashbolt R, Gregory J & OzFoodNet Working Group (2007) A multi-centre prospective case-control study of *Campylobacter* infection in persons aged 5 years and older in Australia. *Epidemiol and Infect* 135:978–988.
- Stern NJ (1992) Reservoirs for *Campylobacter jejuni* and approaches for intervention in poultry, p. 49–60. In I. Nachamkin, M. J. Blaser, and L. S. Tompkins (ed.), *Campylobacter jejuni: current status and future trends*. American Society for Microbiology, Washington, DC.
- Stern NJ & Robach MC (2003) Enumeration of *Campylobacter* spp. in broiler feces and in corresponding processed carcasses. *J of Food Protect*, 66:1557-1563.
- Studahl A, Andersson Y (2000) Risk factors for indigenous *Campylobacter* infection: a Swedish case-control study. *Epidemiol Infect* 125:269–275.
- Suzuki H, Yamamoto S (2009) *Campylobacter* contamination in retail poultry meats and by-products in the world: a literature survey. *The J of Vet Med Sci / The Japanese Soc of Vet Sci* 71:255-261.
- Takahashi R, Shahada F, Chuma T & Okamoto K (2006) Analysis of *Campylobacter* spp. contamination in broilers from the farm to the final meat cuts by using restriction fragment length polymorphism of the polymerase chain reaction products. *Intern J of Food Microbiol* 110:240 - 245.
- Tauxe R, Kruse H, Hedberg C, Potter M, Madden J, Wachsmuth K (1997) Microbial hazards and emerging issues associated with produce: a preliminary report to the National Advisory Committee on Microbiologic Criteria for Foods. *J. Food Prot.* 60, 1400–1408.
- Tompkins BJ, Wirsing E, Devlin V, Kamhi L, Temple B, Weening K, Cavallo S, Allen L, Brinig P, Goode B, Fitzgerald C, Heiman K, Stroika S, Mahon B (2013) Multistate outbreak of *Campylobacter jejuni* infections associated with undercooked chicken livers- Northeastern United States, 2012. *MMWR: Morbidity & Mortality Weekly Report*; 62(44):874
- Vally H, Hall G, Scallan E, Kirk MD & Angulo FJ (2009) Higher rate of culture-confirmed *Campylobacter* infections in Australia than in the USA: is this due to differences in health-care-seeking behavior or stool culture frequency? *Epidemiol and Infect* 137:1751-1758.
- Van Asselt ED, Jacobs-Reitsma WF, van Brakel R, van der Voet H & van der Fels-Klerx HJ (2008) *Campylobacter* prevalence in the broiler supply chain in the Netherlands. *Poultry Sci* 87:2166-2172.
- Van de Giessen AW, Bloemberg BP, Ritmeester WS & Tilburg JJ (1996) Epidemiological study on risk factors and risk reducing measures for *Campylobacter* infections in Dutch broiler flocks. *Epidemiol and Infect* 117:245–250.
- Van de Giessen AW, Tilburg JJ, Ritmeester WS & van der Plas J (1998) Reduction of *Campylobacter* infections in broiler flocks by application of hygiene measures. *Epidemiol and Infect* 121:57–66.
- Van Gerwe TJWM, Mifflin, JK, Templeton JM, Bouma A, Wagenaar JA, Jacobs-Reitsma WF, Stegeman JA & Klinkenberg D (2009) Quantifying transmission of *Campylobacter jejuni* in commercial broiler flocks. *Appl and*

- Environm Microbiol 75:625-628.
- Van Nierop W, Dusé AG, Marais E, Aithma N, Thothobolo N, Kassel M, Stewart R, Potgieter A, Fernandes B, Galpin JS & Bloomfield SF (2005) Contamination of chicken carcasses in Gauteng, South Africa, by *Salmonella*, *Listeria monocytogenes* and *Campylobacter*. Intern J of Food Microbiol 99:1-6.
- Wallace J, Stanley K, Currie J, Diggle P & Jones J (1997) Seasonality of thermophilic *Campylobacter* populations in chickens. J of Appl Microbiol 82:224–230.
- Wedderkopp A, Nielsen EM & Pedersen K (2003) Distribution of *Campylobacter jejuni* strains Penner serotypes in broiler flocks in broiler flocks 1998-2000 in a small Danish community with special reference to serotype 4-complex. Epidemiol Infect 131:915-921.
- Weltman A, Longenberger AH, Moll M, Johnson L, Martin J, Beaudoin A (2013) Recurrent outbreak of *Campylobacter jejuni* infections associated with a raw milk dairy--Pennsylvania, MMWR: Morbidity & Mortality Weekly Report;62(34):702.
- World Health Organization, WHO (2011) Fact sheet N°255: *Campylobacter*. Viewed 8 March 2014. <http://www.who.int/mediacentre/factsheets/fs255>
- World Health Organization, WHO (2013) The global view of campylobacteriosis: report of an expert consultation. Available at: www.who.int/iris/bitstream/10665/80751/1/9789241564601_eng.pdf
- Wilson IG, Moore JE (1996) Presence of *Salmonella* spp. and *Campylobacter* spp. in shellfish. Epidemiol Infect 116:147–153.
- Yamashiro T, Nakasone N, Higa N, Iwanaga M, Insisiengmay S, Phounane T, Munnalath K, Sithivong N, Sisavath L, Phanthauamath B, et al. (1998) Etiological study of diarrheal patients in Vientiane, Lao People's Democratic Republic. J Clin Microbiol 36(8):2195-2199.
- Yang JR, Wu HS, Chiang CS, Mu JJ (2008) Pediatric campylobacteriosis in northern Taiwan from 2003 to 2005. BMC Infectious Diseases, 8:151
- Zimmer M, Barnhart H, Idris U & Lee MD (2003) Detection of *Campylobacter jejuni* strains in the water lines of a commercial broiler house and their relationship to the strains that colonized the chickens. Avian Dis 47:101-107
- Zisidis N (2011) Surveillance study on campylobacter infestation in poultry, PhD Thesis, University of Ioannina, Greece <http://thesis.ekt.gr/thesisBookReader/id/26917#page/1/mode/2up>
- Zoonosis Centre (2012) Zoonoses in Finland in 2000-2010. Viewed 25 February 2014. http://www.zoonosikeskus.fi/attachments/zoonosoit/zoonosesinfinland_final_
- Zweifel MAZ, Stephan R (2004) Prevalence and characteristics of Shiga toxin-producing *Escherichia coli*, *Salmonella* spp. and *Campylobacter* spp. isolated from slaughtered sheep in Switzerland. Int J Food Microbiol 92:45–53.
- Zweifel C, Scheu KD, Keel M, Renggli F & Stephan R (2008) Occurrence and genotypes of *Campylobacter* in broiler flocks, other farm animals, and the environment during several rearing periods on selected poultry farms. Intern J of Food Microbiol 125:182-187.