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Food, Fish and Campylobacteriosis

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Abstract

Food is a necessity of human beings, and the consumption of food is aimed at obtaining energy and nutrients necessary for the growth and proper functioning of the body. However, food can also be a vehicle for various diseases, and the causal agents can have physical, chemical or biological origin with relevance to health due to their incidence, mortality and negative consequences in the population. Bacteria are the main agents of biological origin associated with foodborne diseases. Among these microorganisms are species of the genus *Campylobacter*, which cause a zoonosis with one of the highest incidences globally, known as Campylobacteriosis. This document provides an overview of foodborne diseases, specifically the causal agents of Campylobacteriosis, including the different measures of control and prevention for this disease in different foods such as poultry, milk, meat, and fish, among others. It also covers the phenomenon of resistance to antimicrobials by these pathogens and the health implications to consumers. The above can generate and maintain safety practices in food production for the protection of public health in different regions around the world.

Keywords: *Campylobacter*; Fish; Foodborne disease; Food safety

1 Introduction

Food is a necessity for human beings, and food consumption is aimed at obtaining energy and nutrients necessary for the growth and proper functioning of the body. However, food can also be contaminated by various agents harmful to the consumer's health, resulting in different diseases. Food safety, together with nutrition, organoleptic qualities and commercial processes, are the characteristics that make up the integral qualities of foods that do not cause illness to the person who consumes them (Fuente-Salcido & Corona, 2010; Jorquera, Galarce & Borie, 2015). Food security, nutritional value and food safety are concepts currently considered a global priority and are related to the different phases of the food chain, such as procedures in agricultural production, livestock management, aquaculture and fishing, product manipulation, processing, conservation, transport, and distribution (Gentile, 2010; Palomino & Muñoz, 2014; WHO, 2018a). Contaminated food generates a vicious cycle of illness and malnutrition, which affects the general population, specifically children and the elderly; therefore, access to safe and nutritious food in quantity becomes essential to maintain life and promote good health (WHO, 2018a). This document is an overview of foodborne diseases, specifically the causal agents of Campylobacteriosis, and includes the different measures of control and prevention of this disease for different foods such as poultry, milk, meat, and fish, among others. It also covers the phenomenon of

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resistance to antimicrobials by these pathogens and the health implications for consumers. The above can generate and maintain safety practices in food production for the protection of public health in different regions around the world.

2 Foodborne diseases

Foodborne diseases (FD) are considered a serious public health problem worldwide due to high levels of morbidity, mortality and economic costs in health services (Alerte et al., 2012; Garcia-Huidobro, Carreno, Alcayaga & Ulloa, 2012; Jorquera et al., 2015; Palomino & Muñoz, 2014). Approximately 250 FD-causing agents have been described, including chemical, physical and biological agents; the latter being specifically bacteria such as Salmonella spp., *Listeria monocytogenes, Vibrio cholerae, Staphylococcus aureus, Campylobacter* spp., *Shigella* spp., and *Escherichia coli*, which are frequently related to outbreaks (Garcia-Huidobro et al., 2012; Jorquera et al., 2015; WHO, 2018a).
Factors such as globalization, the development of new products and manufacturing processes, changes in food habits, the growing demand for ready-to-eat foods, new forms of transmission, the emergence of vulnerable population groups, and the increase in resistance to antimicrobial compounds by pathogenic microorganisms have contributed to the increase of these diseases (Jorquera et al., 2015; Palomino & Muñoz, 2014). It is estimated that around the world, 600 million people get sick from eating contaminated food and 420,000 deaths occur from this same cause every year. The availability of safe and nutritious food is essential for the maintenance of life and promotion of good health. Currently, food production and supply chains have an international presence; therefore, collaboration among governments, producers, industry and consumers is a fundamental part of actions related to food safety and disease prevention (WHO, 2018a).

3 *Campylobacter* generalities

The genus *Campylobacter* consists of several different species of clinical and economic importance, including *Campylobacter fetus, Campylobacter coli, Campylobacter concisus, Campylobacter curvus, Campylobacter gracilis, Campylobacter helveticus, Campylobacter hominis, Campylobacter hyointestinalis, Campylobacter jejuni, Campylobacter lanienae, Campylobacter lari, Campylobacter mucosalis, Campylobacter rectus, Campylobacter showae, Campylobacter sputorum, Campylobacter upsaliensis, Campylobacter insulaenigrae, Campylobacter pyloridis, Campylobacter avium, Campylobacter subantarticus, Campylobacter canadensis, Campylobacter cunicolurum, Campylobacter volucris, and Campylobacter ureolyticus* (Cabello, 2007; Cecilia, Arreola & Graciela, 2013; Lapierre, 2013). The characteristics presented by these microorganisms are as follows: spherical bacilli form, curved, comma or coccoid shape of 0.2 μm to 0.5 μm in old cultures or 0.2 μm to 5 μm in fresh bacterial cultures, Gram negative, mobile, nonsporulated, noncapsule-forming, and microaerophilic. They present surface immunogens as "O" antigens that distinguish the 23 serotypes and are considered a pathogenicity factor. The antigen "H" is present in flagella protein. They are metabolically oxidase-positive and can reduce nitrates, produce hydrogen sulfide, and hydrolyze hippurate. They do not ferment or oxidize carbohydrates, presenting a negative reaction to methyl red, Voges-Proskauer and gelatin hydrolysis; therefore, energy is obtained from amino acids or cycle intermediaries of tricarboxylic acids. Most strains are resistant to cephalothin and may be urea-negative, except for some strains of *Campylobacter lari*. Prolonged exposure to air and water causes them to take the shape of cocci, which are difficult to grow and may even be uncultivable. They have a growth temperature range from 30 ^{o}C to 45 ^{o}C and pH range from 5 to 8; *C. jejuni, C. coli and C. lari* are thermophilic with optimum growth at 42 ^{o}C and 43 ^{o}C, but they do not grow at temperatures below 25 ^{o}C. The species of medical and veterinary importance are *C. jejuni, C. coli* and *C. lari*. *C. jejuni* is divided into two subspecies: *C. jejuni jejuni*, referred to simply as *C. jejuni*, and *C. jejuni doylei*. The infectious disease caused by *Campylobacter* spp., is called Campylobacteriosis (Cabello, 2007; CDC, 2017; Cervantes García & Cravioto, 2007; Elika, 2013; Epps et al., 2013; Gutierrez Castillo, Paasch Martinez & Calderon Apodaca, 2008; Lapierre, 2013).

Campylobacter spp., is a ubiquitous microorganism and can be found in water, soil, and the intestinal tract of cats, dogs, birds, cattle, swine, rodents, monkeys, wild birds and humans. In animals, bacteria passing through the body are deposited in the feces and circulate through the environment, with birds being one of the main reservoirs and sources of infection (Cecilia et al., 2013; Cervantes García & Cravioto, 2007; Epps et al., 2013; USDA, 2011).

The factors related to the ability to cause disease to a host by these bacteria are as follows: motility through the presence of flagella, which is required in the colonization of the small intestine and subsequent transfer to the colon of a host; adhesion through external membrane proteins, flagellins and capsules; invasion and toxigenicity through the production of toxins; in addition, lipopolysaccharide (LPS) is endotoxic (Cabello, 2007; Cecilia et al., 2013; Cervantes García & Cravioto, 2007; Lapierre, 2013).

Campylobacteriosis is considered one of the main zoonoses with the highest prevalence of diarrhea and gastroenteritis in the world and is the second most frequent foodborne disease in countries such as the United States of America, with 1.3 million cases each year, where *C. jejuni* is the strain regularly associated with human infections (CDC, 2017; Gutierrez Castillo et al., 2008; Lapierre, 2013; USDA, 2011; WHO, 2017). In the European Union (EU), this foodborne disease is the most frequently reported with more than 190,000 cases in humans per year, estimating a cost for public health systems and loss of productivity of 2.4 billion euros per year (EFSA, 2018).

This disease is caused by the consumption of contaminated water and food of vegetable or animal origin, such as unpasteurized milk, seafood, fish, raw or undercooked meat, and fruits and vegetables irrigated with contaminated water or in contact with feces of infected animals (EFSA, 2018; Elika, 2013; Lapierre, 2013; Soares & Gonçalves, 2012; USDA, 2011; WHO, 2017).

It is estimated that an inoculum of 10^4 cells is sufficient for infection by *Campylobacter* spp. to occur, and in some cases, *Campylobacter* spp., is highly infectious, giving rise to disease with only 500 cells depending on the strain, damage to the cells by a stressful environment and host susceptibility (Hunt Jan, Abeyta & Tran, 2001; Mardones P. & Lopez-Martin, 2017). Campylobacteriosis is characterized by symptoms such as diarrhea, which is generally bloody, abdominal pain, dehydration, weakness, malaise, fever, headache, nausea and/or vomiting that appears between 5 and 10 days after infection with a usual duration of 3 to 6 days; mortality is low but occurs in a greater proportion in groups considered high-risk populations, such as children, elderly, and people with chronic conditions and immunosuppressed systems. Campylobacteriosis can generate complications manifesting as bacteremia, urinary tract infection, pneumonia, peritonitis, hepatitis, pancreatitis, abortion, reactive arthritis and neurological disorders, such as Guillain-Barré syndrome (Cabello, 2007; CDC, 2017; Epps et al., 2013; WHO, 2017).

The therapeutic treatment of this disease is not usually required since the disease is short-lived and self-limiting. However, when the symptoms are prolonged or very serious, antimicrobial therapy is necessary. The antibiotics of first choice are macrolides, such as erythromycin, and fluoroquinolones, such as ciprofloxacin. However, some species of *Campylobacter* spp., have been shown to be resistant to glycopeptides, penicillin, ampicillin, cephalosporins, chloramphenicol, and fluoroquinolones, among others, making the clinical management of Campylobacteriosis complicated (Cecilia et al., 2013; Garcés Vega, Klotz Ceberio, Mantilla Pulido, Ramírez Rueda & Romero Prada, 2013; Weiler et al., 2017).

4 Fish and health

Fish is a food with a special dichotomy. On one hand, it is considered highly nutritious, has highly digestible proteins and a high biological value, and contains lipids (polyunsaturated), vitamins and minerals, which make it part of a healthy diet. On the other hand, these properties also make it a highly perishable food, susceptible to deterioration (microbial, autolytic and chemical) and contamination, making it high-risk to the health of consumers (Amanda Thaís Ferreira et al., 2017; FAO, 1998; Soares & Gonçalves, 2012). Capture fisheries and aquaculture are important sources of food, nutrition, income and livelihoods for millions of people globally (FAO, 2016). Fish acquire the microbiota of the natural environment where they live, and this microbial population may include different human pathogens. If fish are captured in areas near the coast or regions with a high human population density or produced through inappropriate practices in aquaculture and fisheries, including postharvest phases, handling, processing, storage, transport and marketing, the result may be foods that deteriorate faster, are of low quality and are vehicles for various pathogenic microorganisms such as *C. jejuni, E. coli, L. monocytogenes, Staphylococcus spp., Salmonella spp., V. cholerae*, as well as viruses (enteroviruses) and parasites (Protozoa, Trematodes, Cestodes and Nematodes). This places human health at high risk due to the consumption of raw meat or food subjected to inadequate preparation or cooking procedures (Ferre, 2016; Fos Claver, 2000; Frasao, Marin & Conte-Junior, 2017; Manuel Romero-Jarero & del Pilar Negrete-Redondo, 2011; REMA, 2017; Silva et al., 2016; Soares & Gonçalves, 2012). In some countries in South America, such as Chile, an epidemiological study conducted in the metropolitan regions found that 12,196 cases of foodborne diseases occurred from 2005 to 2010, of which 30.5% had fish and shellfish as the causal agents. Illness was of biological origin, mainly from bacteria such as *Salmonella* spp., *Shigella* spp., *Vibrio parahaemolyticus, Listeria* spp., *Staphylococcus* spp., and parasites (i.e. Giardia spp. and *Sarcocystis* spp.) (Alerte et al., 2012). In European countries, such as Spain, in the period from 2008 to 2011, 30,219 cases of food-related diseases were recorded, and fish was involved in 6% of all cases, with bacteria being identified as the main biological agents, including *Salmonella* spp., *Campylobacter* spp., *Staphylococcus* spp., and *Clostridium perfringens* (Espinosa, Varela, MartInez & Cano, 2014).

5 Control and prevention of foodborne diseases

Around the world, different standards, guidelines and certifications have been developed and implemented that assume an increasingly important role in the international food trade. Evidence of their use is commonly requested to guarantee food safety, quality and environmental sustainability in the growing food industry, including that of fish and fish products. Some of these prevention and control measures have been developed and are issued by international organizations such as the World Health Organization (WHO), which suggests good practices in sanitary control of operations in the production of safe food (good agricultural practices, good practices in manufacturing, and the Hazard Analysis and Critical Control Point (HACCP) system). The Food and Agriculture Organization of the United Nations (FAO) through the Codex Alimentarius has developed guidelines and codes of practice for food production of unprocessed, semi-processed or processed foods for distribution to the consumer or as raw material (PAHO, 2016; Racua, 2018). In addition, the International Organization for Standardization (ISO) developed standards such as ISO 22000, as well as other recommendations and certification programs accepted globally, such as Safe Quality Food (SQF), British Retail Consortium (BRC), International Food Standard (IFS), PrimusGFS, Global G.A.P, and Quality Certification Services (QCS), among others, with the purpose of producing, distributing and commercializing safe foods for the health of the consumer (PAHO, 2016; Racua, 2018).

It is considered that food production animals (poultry, cattle and swine) are the main source of infections by *Campylobacter* spp. in humans (Epps et al., 2013). Throughout the food processing chain (from the farm to the consumer´s table) from slaughter, through food processing, until its preservation and manipulation prior to consumption, there are numerous possibilities for transmission of infection by *Campylobacter* spp.; therefore, it is necessary to implement procedures for good hygiene practices during all stages of the food processing chain, including the implementation of control systems, such as HACCP, the establishment of microbiological criteria in raw materials and finished products and the provision of information and/or continuous training of food handlers and the general population on the handling, preparation and preservation of food prior to consumption (Elika, 2013; USDA, 2013).

In food legislation, as a measure of prevention and control of foodborne diseases, microbiological specifications have been established for foods considered to be at risk of contamination by *Campylobacter* spp. to safeguard public health in Europe, for example, in 2003, the Recommendation of the Commission 2004/24 / CE (DOCE 19/12/03) in the program of official control of food products was established through the official journal of the European Union. It was announced that starting in 2004, the member states of the community would carry out inspections and controls and, if applicable, collect and analyze samples to assess the bacteriological safety of dairy products, such as cheeses made from raw milk or under thermal treatment, and assess the bacteriological safety of refrigerated poultry meat related to thermophilic *Campylobacter*. In addition, the latest version of the standard developed by the International Standardization Organization, ISO 10272, was recommended as a method for the detection of this pathogen. It also established food safety criteria in foods, with the microbiological limit of "absence" in 25 g samples of cheese based on raw milk, cheese based on milk subjected to heat treatment less than pasteurization and fresh poultry meat. Subsequently, the regulation (CE) 2073/2005 of the commission was presented through the official journal of the European Union on November 15, 2005, relating to the microbiological criteria and methods of analysis applicable to different food products and microorganisms. In addition, the regulation (CE) 853/2004, by which specific recommendations of hygiene of foods of animal origin are established, regulation (CE) 852/2004 on the hygiene of alimentary products, and regulation (CE) 1935/2004 on materials and objects intended to contact food were established. This legislation regarding food hygiene should be implemented by food producers and processors, including those of fish and shellfish, to provide safe food for the health of the population.

In Latin American countries, such as México, the consumption of meat products, including those from poultry, is considered a common source of various food pathogens, including *Campylobacter* spp. Sanitary control measures are usually carried out on different food products, including meat, for food pathogens such as Salmonella spp., but not for the control of *Campylobacter* species (Rodriguez Ceniceros, Gomez Hernandez & Vazquez Sandoval, 2016). For example, the official Mexican standard "NOM-213-SSA1-2002" focuses on sanitary specifications and testing methods for processed meat products, and the "NOM-243-SSA1-2010" standard states the sanitary specifications and test methods for foods of animal origin, such as milk and different products. The standard "NOM-242-SSA1-2009" focuses on fresh, chilled, frozen and processed fishery products regarding sanitary specifications and test methods, and finally, the standard "NOM-210-SSA1-2014" outlines microbiological methods for the determination of pathogenic indicators and pathogenic microorganisms. These standards should be considered in order to strengthen the measures of surveillance and control of this pathogen in food, contributing to the health protection of the population. Standard "NOM-251-SSA1-2009" establishes the minimum requirements of good hygiene practices that must be observed in the processing of food, beverages or food supplements and their raw materials in order to avoid contamination throughout the process, which includes the HACCP system and guidelines for its application. The detection of microorganisms in food is an essential part of any quality control and safety process and is an important element in epidemiological research in order to carry out surveillance, control microorganisms and prevent disease (Rodriguez Ceniceros et al., 2016).

6 Analysis of food in the laboratory

The measures for the control and prevention of Campylobacteriosis include analysis in a microbiological food laboratory, where the detection and isolation of *Campylobacter* is generally performed by isolation and confirmation is by biochemical, molecular and proteomic tests (Dudzic et al., 2016; Mandrell et al., 2005; Rodriguez, Guzmon Osorio & Verjan, 2015; Weiler et al., 2017). Different standardized methods have been developed that involve enrichment

Table 1: Different tests for phenotypic identification of species of the genus *Campylobacter* (Hunt Jan, Abeyta & Tran, 2001).

Characteristics	Microorganism *C. jejuni*	*C. jejuni* subsp. Doylei	*C. coli*	*C. lari*	*C. fetus* subsp. fetus	*C. hyointestinalis*
Growth at 25 ^oC	-	±	-	-	+	A
Growth at 35 ^oC to 37 ^oC	+	+	+	+	+	+
Growth at 42 ^oC	+	±	+	+	A	+
Nitrate reduction	+	-	+	+	+	+
NaCl 3.5%	-	-	-	-	-	-
H_2S, TSI	-	-	A	-	-	+H
Catalase	+	+	+	+	+	+
Oxidase	+	+	+	+	+	+
Motility	+(81%)	+	+	+	+	+
Hippurine hydrolysis	+	+	-	-	-	-

Symbols: +, 90% or more of strains are positive; -, 90% or more of strains are negative; A, 11-89% of strains are positive; H: Small amount of H_2S on fresh (<3 days) TSI slants; H_2S hydrogen sulfide, Triple sugar iron agar (TSI).

and isolation stages in selective culture media as well as the management of specific culture conditions related to temperature, O2 requirements and subsequent biochemical confirmatory tests (Table 1). Methods developed by Hunt Jan et al. (2001), are reported in the Bacteriology Analytical Manual (BAM) of the Food and Drug Administration of the United States of America (US FDA) for the isolation, identification and confirmation of *Campylobacter* spp., the laboratory guide of the United States Department of Agriculture (USDA) (method MLG 41.04) and the Food Safety and Inspection Service (FSIS) (USDA, 2016). Methods for the detection (method 10272-1) (Figure 1) and colony counts of the food pathogen (method 10272-2) (Figure 2) are reported by the International Organization for Standardization (ISO); the latter method being the gold standard for detection and isolation. However, in order to avoid the inconvenience of the time required for analysis by traditional microbiological methods and to obtain information more quickly for decision-making regarding aspects of the health and safety of water and food, molecular methods have also been developed, which involve the polymerase chain reaction (PCR) and its different variants to identify genes, such as *hypO, glyA, sapB2, fla, rpoB,* 23S rRNA, and 16S rRNA, among others, and immunoassays (de Boer, Rahaoui, Leer, Montijn & Van der Vossen, 2015; Frasao et al., 2017; Park et al., 2011; Rodriguez et al., 2015; Rojas-Herrera & González-Flores, 2006). Molecular methods, such as restriction fragment length polymorphism (RFLP), amplified fragment length polymorphism (AFLP), multilocus sequence typing (MLST), whole-genome sequence (WGS) and pulsed-field gel electrophoresis (PFGE) can be used in the typing of food pathogens; the latter being common for the typing of *Campylobacter* spp., useful and relevant in the epidemiological analysis of outbreaks of foodborne diseases (Behringer, Miller & Oyarzabal, 2011; Frasao et al., 2017; Lahti, Löfdahl, Ågren, Hansson & Olsson Engvall, 2017; Rodriguez et al., 2015; Taboada, Clark, Sproston & Carrillo, 2013).

7 Resistance to antimicrobials

Resistance to antimicrobials is the ability to resist and survive the action of antimicrobial molecules by microorganisms, this phenomenon is observed mainly in bacteria. Resistance to antimicrobials is considered a global threat to human

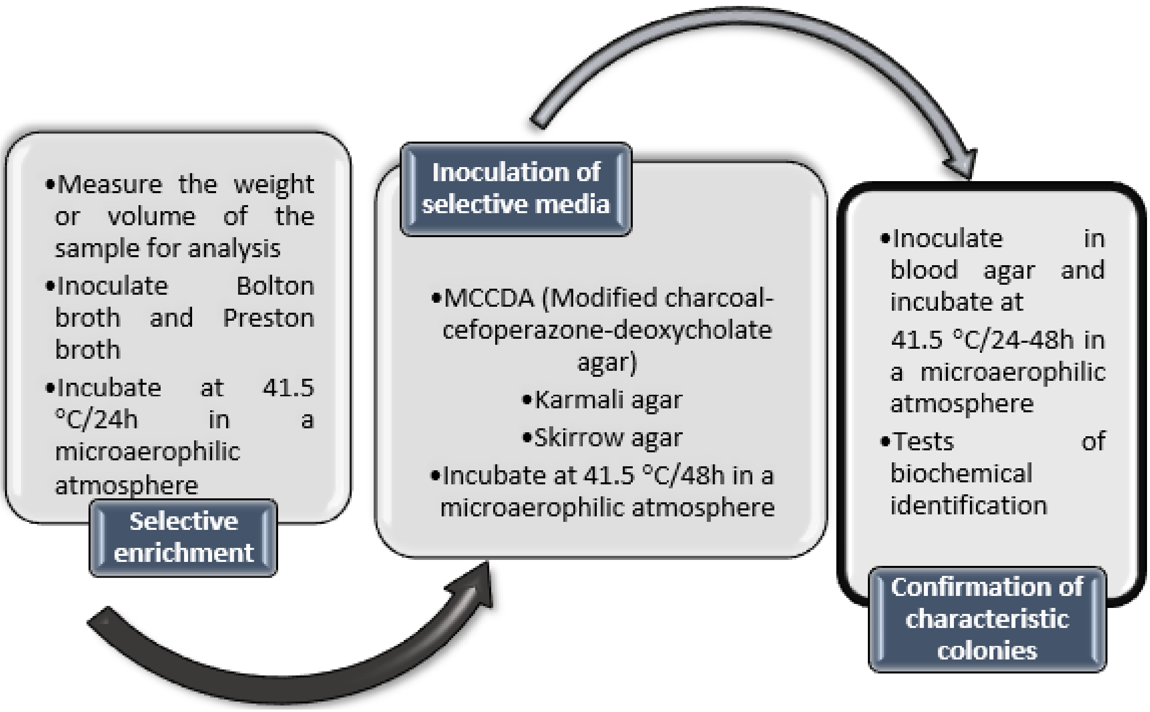

Figure 1: General diagram of detection of *Campylobacter* spp., in food (ISO 10272-1, 2017); (SAA, 2017a)

and animal health. It is estimated that 500,000 people die each year from causes related to antimicrobial resistance (Cires, 2002; FAO, 2018). In addition, this phenomenon influences clinical procedures, such as organ transplant, cancer chemotherapy, diabetes treatment and major surgery, which increases the cost of health care, hospital stays, the need for more intensive care and mortality (WHO, 2018b). This characteristic of microorganisms also impacts areas of food safety, food security, and economics, since food contributes to the development and spread of antimicrobial resistance as a potential route of exposure for the entire population (FAO, 2018).
Reported mechanisms of antimicrobial resistance are genetic variability, modification of membrane permeability, excretion pumps, enzymatic modification of the compound, and modification of the ribosomal target or composition alteration of the site of action; several of these mechanisms have been developed and observed in strains of resistant *Campylobacter* spp., of clinical or food origin (Becerra, Plascencia Hernandez, Luevanos, DomInguez & HernAndez, 2009; Cires, 2002; Tafur, Torres & Villegas, 2008; Wieczorek & Osek, 2013). Antimicrobial resistance is transmitted between microorganisms through the acquisition of genetic material by conjugation, transformation or transduction processes of plasmids, transposons and integrons that contribute to the incorporation of resistance genes between microorganisms of the same genus (horizontal transmission) or different genera (vertical transmission) (Becerra et al., 2009; Cires, 2002; Pérez-Cano & Robles-Contreras, 2013).
In recent years, the resistance of different pathogens in foods, such as *Salmonella* spp., *E. coli*, and *L. monocytogenes*, has been reported (De Nes, Riboldi, Frazzon, d'Azevedo & Frazzon, 2010; Puig Peña, Espino Hernández

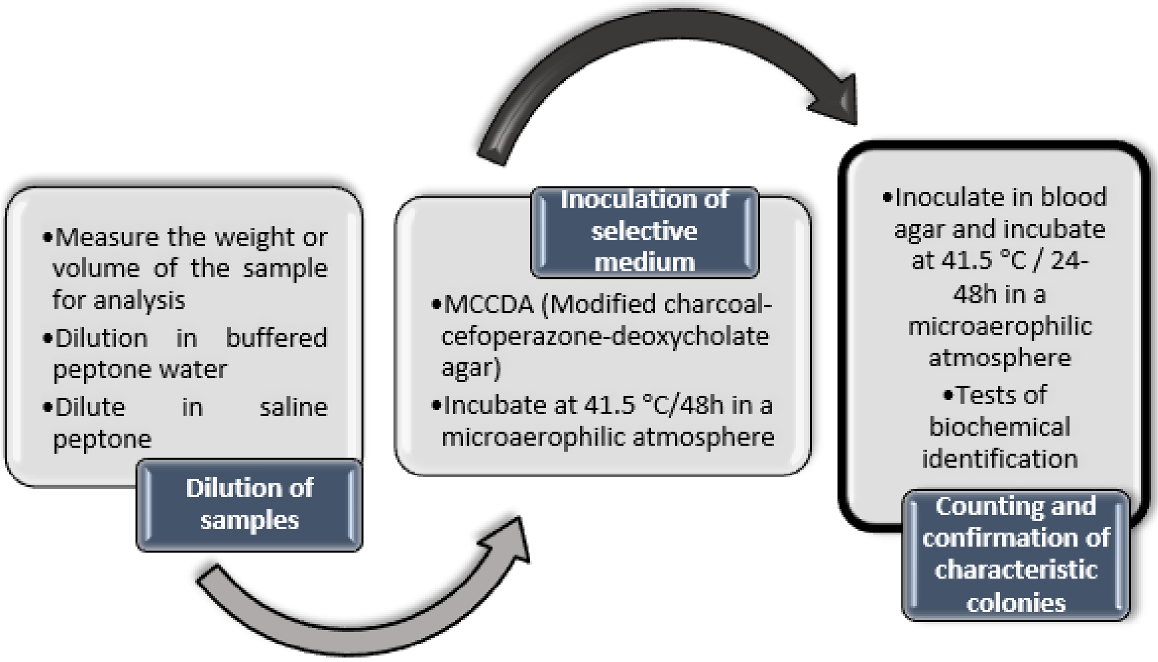

Figure 2: General diagram of quantification of *Campylobacter* spp., colonies in food (ISO 10272-2 (2017); SAA (2017b))

& Leyva Castillo, 2011). Studies around the world on *Campylobacter* spp. of human and animal origin have shown resistance to antimicrobials, such as erythromycin, tetracycline, ampicillin and quinolones (Dallal et al., 2010; Fernandez, 2011; Gonzalez-Hein, Cordero, Garcia & Figueroa, 2013; Wieczorek & Osek, 2013).

Microorganisms are reservoirs of antimicrobial-resistance genes which can potentially be exchanged between other pathogenic and commensal bacteria. The indiscriminate use of antibiotics in humans (clinical) and in animal production has been established as protective or preventive, therapeutic and growth promoting, resulting in the emergence and spread of antibiotic resistance among various pathogens, including *Campylobacter* spp., in areas involved in animal production for food (mainly in poultry) and the environment. This resistance can, therefore, be transmitted through food production and consumption, becoming a global risk for human health (Epps et al., 2013; Mardones P. & Lopez-Martin, 2017; Wieczorek & Osek, 2013). To control this phenomenon in microorganisms, action plans, strategies, guidelines, recommendations and codes of practice have been developed at the global level by the World Health Organization (WHO), the United Nations Food and Agriculture (FAO)-Codex Alimentarius and the World Organization for Animal Health (OIE) with the aim of promoting best practices that reduce or control the emergence and spread of antimicrobial resistance through the optimal use of these compounds in human and animal health, with regulations for the use of medicine and waste management, as well as in the production of food with good hygiene practices in the agricultural, livestock, and aquaculture sector, which are considered key to achieving food safety and combating resistance to antimicrobials (FAO, 2018; WHO, 2018b).

8 Final comments

Foodborne diseases caused by different agents of biological origin constitute a serious problem for the health sector at a global level due to their incidence, mortality and negative repercussions in the economic and productive sector, in addition to the appearance of causal agents (mainly bacteria) resistant to antimicrobials, which aggravates the problem. Governments and international organizations have developed and implemented control and surveillance strategies and actions that differ in the production of safe food for the health of consumers.

Campylobacter spp. is considered one of the zoonoses, called Campylobacteriosis, with greater incidence around the world. It is a disease transmitted by foods such as fruits, fish, vegetables, meat mainly of avian origin, dairy and derivatives for which bacteria have also shown resistance to different antibiotics.

Global measures for the control and prevention of Campylobacteriosis and resistance to antimicrobials by their causative agents are mainly focused on the application of hygiene practices along the food production chain, including good practices for agriculture and livestock production, fisheries, aquaculture, and manufacturing, as well as the implementation of operational control systems as HACCP. Also important is regular reporting and promotion of handling, preparation and correct conservation of foods at home directed to the food handler and final consumer. Finally, the joint action of governments, the food industry, and academia in the continual updating, development and optimization of legislation and analytical methods for detection of food pathogens, in regard to the control and prevention of foodborne diseases, should be applied to protect public health.

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