Risk assessment of *Listeria monocytogenes* in poultry and beef

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Abstract

Purpose – A quantitative microbiological risk assessment (QMRA) was developed to estimate the probability of getting listeriosis as a consequence of chicken and beef consumption in Chile. The paper aims to discuss these issues.

Design/methodology/approach – As a first step a deterministic retail-to-home model was constructed for the Chilean susceptible population, including storage, cross-contamination and cooking. Next, two probabilistic models were developed, including variability and/or the uncertainty of some of the parameters. The probabilistic models were analyzed by Monte Carlo simulations with 100,000 iterations.

Findings – Of the total susceptible population used in the model (2.81 million people), the deterministic model estimated 11 and two listeriosis cases because of beef and poultry consumption, respectively and the variability model estimated a mean of 322 and 7,546 cases for beef and poultry consumption, respectively. The uncertainty analysis showed large ranges, with realistic estimates made with an initial concentration of *Listeria monocytogenes* of 0.04-1 CFU/g and a dose-response parameter r ranging from 10-14 to 10-10.

Research limitations/implications – The lack of information was the major limitation of the model, so the generation of it has to be a priority in Chile for developing less uncertain risk assessments in the future.

Practical implications – Raw animal products can be the cause of listeriosis cases if they are not stored, cooked and/or handled properly. Consumer education seems to be an essential factor for disease prevention.

Originality/value – This is the first QMRA made in Chile, and also the first study of listeriosis in non-processed meat.

Keywords Poultry, Chile, Beef, *Listeria monocytogenes*, Listeriosis, Quantitative risk assessment

Paper type Research paper

Introduction

L. monocytogenes is a facultative intracellular pathogen responsible of listeriosis a severe disease with high lethality rates that vary from 11 percent in people of $\leqslant 40$ years old (not including infants and pregnant women) and up to 63 percent in people over 60 years old (Chile Ministry of Health, 2012). Listeriosis mainly affects the elderly, pregnant

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women, newborns and immune-compromised adults causing encephalitis, meningitis, septicemia and abortions (Vasquez-Boland *et al.*, 2001). Because of its severity, it's necessary to implement effective control strategies to minimize its impact in public health. Quantitative microbiological risk assessment (QMRA) is rapidly accumulating recognition as the most practical method for evaluating the probability and consequences of microbial hazards in food (Vose, 2008). The QMRA can be deterministic, where a point estimate is used for each parameter or probabilistic where the parameter is represented by a probability distribution, which describes lack of precise knowledge (uncertainty) and/or natural variation of the parameter (variability) (Vose, 2008).

Listeriosis is usually associated with ready-to-eat (RTE) foods intake such as cheese and cured meats. These foods were responsible for two recent outbreaks in Chile in 2008 and 2009. From years 2010-2013 several outbreaks and sporadic cases has been occurred but no association has been made between the *L. monocytogenes* strains found in patients and RTE foods (Chile Ministry of Health, 2012). The aim of this study was to study the risk of getting listeriosis because of meat consumption (poultry and beef). These foods have not been associated with listeriosis worldwide, but it was hypothesized that meat may be associated with *L. monocytogenes* illness because of the relations found in our laboratory, where ground beef (Foerster *et al.*, 2012) and poultry (Foerster *et al.*, 2013) strains showed highly similar profiles with human listeriosis strains as tested by pulsed field gel electrophoresis (PFGE). Other points of interest in our setting are that consumption and export of meat shows a large increase (Chile Ministry of Agriculture, 2013), and our laboratory has found high prevalence of *L. monocytogenes* in local supermarkets: 37.5 percent in ground beef (Foerster *et al.*, 2012), 54 percent in fresh chicken and 10 percent in frozen chicken (unpublished data). This information is important especially when most local consumers have little knowledge about the risks of these products when eaten inadequately cooked and/or inappropriately handled in the kitchen.

To estimate the number of illness caused by *L. monocytogenes* due to poultry and beef consumption we developed three different simplified QMRA models: a deterministic, a variability and an uncertainty model. The main goals were to compare the results between the different models, as well as to evaluate the relative risk between poultry and beef consumption. With the limited amount of data available, only a reduced number of variables were chosen to perform the variability and uncertainty analysis.

Material and methods

Models

Deterministic model. This model was based on the swift QMRA (Evers and Chardon, 2010) which includes parameters from retail to home. These parameters are shown in Table I with their symbol and value or formula. The schematic diagram of the model is shown in Figure 1.

Bacterial growth in raw meat was evaluated by a primary growth model (Equation (1)) and secondary gamma model (Equation (2)) (van Gerwen and Zwietering, 1998):

$$G = e^{(t \times mu)} \tag{1}$$

where G is the growth factor of *L. monocytogenes*; mu the *L. monocytogenes* specific growth rate (h^{-1}); t the storage time in home refrigerator (h).

$$mu = mu_{ref} \times \left((T - T_{min})/\left(T_{ref} - T_{min}\right)\right)^2 \tag{2}$$

Parameters	Symbol	Value or formula
Susceptible population of Chile	Population	2.81 million people
No. portions/person/year consumed	No. portions/ person/year	Beef: 144; Poultry: 180
Total portions consumed	Np	Population × No. portions/ person/year
Prevalence of *Listeria monocytogenes* (LM) in raw meat	P	Beef: 37.5%; Poultry: 54%
Number of portions that are contaminated	PC	Np × P
Size of portion	M	Beef: 153.1 g; Poultry: 200 g
Initial concentration of LM in raw meat	C	Determinist model: 0.1 CFU/g
CFU in contaminated portion	CC	M × C
Growth of LM in storage	G	See Equation 1
% Portions that potentially contaminate the environment	CX	94.5%
Number of portions that contaminate the environment	NCX	PC × CX
Transfer factor: % of CFU that contaminates the environment and food and are consumed	FCC	Determinist model: 0.0456%
Number of portions that not contaminate the environment	NC	PC × (1-CX)
CFU of LM in portion	[CP]	CC × G × (1-FCC^0.5)
CFU of LM in portion because cross-contamination	[XC]	CC × G × FCC
% Consumed done	%C	Beef: 85.9%; poultry: 98.8%
% Consumed half done	%M	Beef: 13.6%; poultry: 0.2%
% Consumed raw	%Cr	Beef: 0.5%; poultry: 0%
Probability of survival of LM after heating	PS	See Equation 4
% LM that survives to done cooking	0%	0%
% LM that survives to half-done cooking	SM	PS
% LM that survives to no cooking (raw)	100%	100%
Probability of infection by a single cell of LM	*r*	Deterministic model: 1.330 × 10E-10
Number of contaminated portions consumed	Y	% Heating (%C,%M or %Cr) x NCX or NC
CFU/ portion		% Survival (SM, 0% or 100%) × [CP]
Dose	N	CFU/portion + [XC]
Probability of infection for ingest one portion	Pinf	see Equation 5
Number of illness		Y × Pinf

Table I. Parameters used in the risk assessment with their symbol and formula

where mu_{ref} is the growth rate at reference temperature T_{ref}. We used two h^{-1} for a T_{ref} 37°C (te Giffel and Zwietering, 1999); T the storage temperature in home refrigerator (°C); T_{min} the minumum growth temperature of *L. monocytogenes*. We used −1.5°C (te Giffel and Zwietering, 1999).

A survival model of *L. monocytogenes* to (possibly inadequate) cooking was conducted using the *D*/*z* thermal inactivation model:

$$D = D_{ref} \times 10^{-((Th-Tref)/Z)} \quad (3)$$

where D is the D-value, decimal reduction time. Time required at a certain temperature to kill 90 percent of the organisms (min). D_{ref} the reference D-value for *L. monocytogenes*

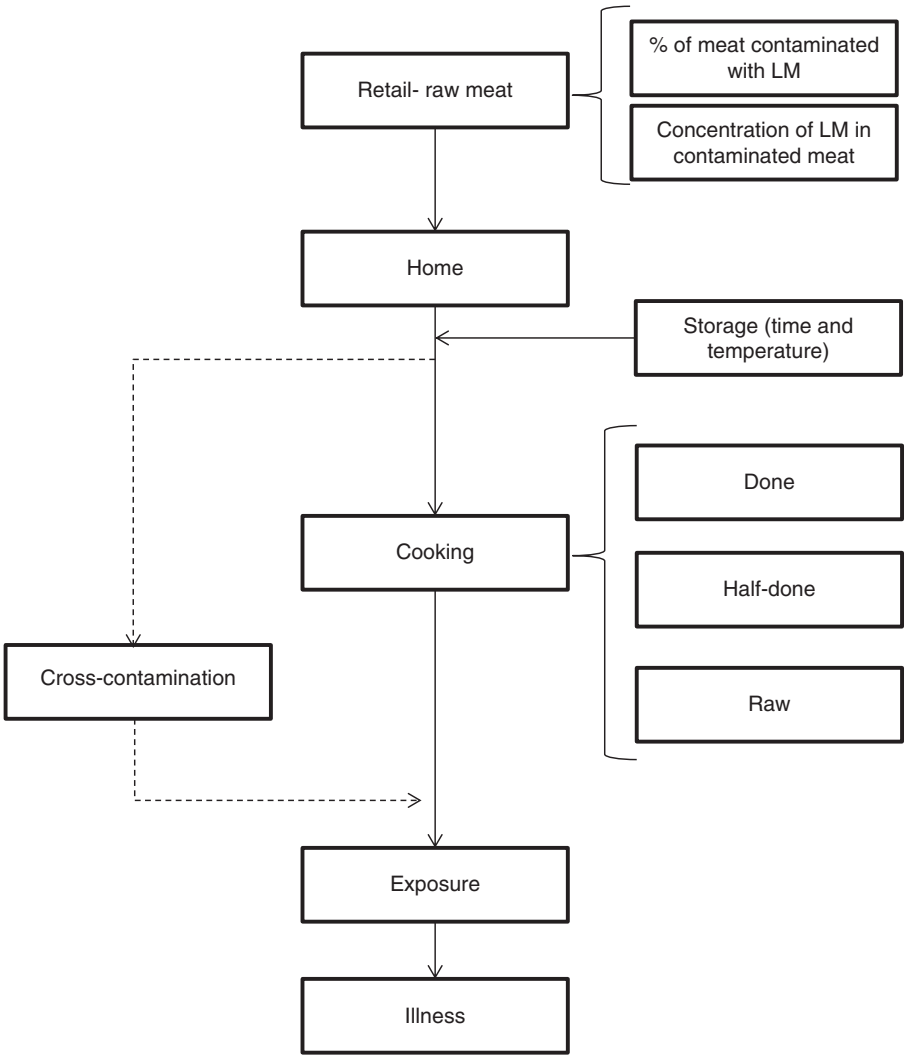


Figure 1.
Schematic diagram of the structure of the model used in the risk assessment. Retail meat with a prevalence and initial concentration of *L. monocytogenes* is stored, cooked and handled by the consumer. The cross-contamination calculated is from a RTE food served with the meat

at a reference temperature T_{ref}. We used chicken leg value for poultry = 0.17 min and steak for beef = 0.14 min, for a reference temperature T_{ref} of 70°C (ICMSF, 1996). T_h the heating temperature (°C). Z the Z-value. Temperature required for one log reduction in the D-value. We used 7°C (van Asselt and Zwietering, 2006).

$$PS = 10^{-(th/D)} \tag{4}$$

where PS is the probability of survival; t_h the heating time (min).

The probability of infection for an ingested dose of *L. monocytogenes* was calculated with the exponential dose-response relationship:

$$P_{inf} = 1 - e^{-rN} \tag{5}$$

where P_{inf} is the probability of infection for ingesting a dose of *L. monocytogenes*; r the probability of infection from a single cell of *L. monocytogenes*; N the *L. monocytogenes* dose.

Variability model. In this model we used the values of the determinist model in all parameters with the exception of the concentration of *L. monocytogenes* in raw meat (*C*) and the cross-contamination of the pathogen from environment to a RTE dish transfer factor (*FCC*). For *C* and *FCC* international data were used and a lognormal distribution was assumed. As foreign data was used, it was assumed that *C* and *FCC* do not vary across countries and that poultry transfer values were the same as beef values. The *C* data were obtained from a study of minced beef and chicken made in Japan by Inoue *et al.* (2000), while *FCC* data were obtained by a chicken fillets with salad preparation study (Nauta *et al.*, 2008), whose values were specified in the annex of the paper of Nauta and Christensen (2011).

Uncertainty model. To study the uncertainty, first we did a sensitive study of the five variables that were considered potentially important in determining the model output: the prevalence (*P*), *FCC*, *C*, portion size (*M*) and probability of infection from a cell of *L. monocytogenes* (*r*). Minimum (min.) and maximum (max.) values from each parameter, to be interpreted as lower and upper limits of a realistic uncertainty range, were obtained from international information in the case of *r* (FAO/OMS, 2000), and the opinion of food microbiology experts of the University of Chile, in the case of *P*, *FCC*, *C* and *M*. The values used in the calculation are given in Table II. To assess uncertainty, these values replaced the values used in the deterministic model for poultry and beef consumption. The differences between the number of illness by *L. monocytogenes*, for the minimum and maximum value of each variable were plotted, as shown in Figure 2. The biggest differences between min. and max. results were from parameters *C* and *r* so these were chosen to do the uncertainty study. In the case of *C* the mean value of the variability model was replaced with five values determined by food microbiology experts of the University of Chile (0.04; 0.1; 1; 100; 1,000 CFU/g). In case of *r* the value of the deterministic model was replaced with 5-95 percent percentiles of international data (Table III) that were assumed and fitted to a lognormal distribution.

Parameter values

Population. The estimation of the susceptible population included people over 60, pregnant women and immune-depressed individuals. The values for people over 60 and pregnant women were taken from the 2012 census estimations of the Chilean National Statistical Institute (Chile INE, 2011). The number of immune-depressed people were obtained by the mortality indicators of malignant tumors, diabetes, chronic pneumonia, cirrhosis and other chronic liver diseases, HIV/AIDS and tuberculosis in a study of

	Minimum	Maximum	Observations
C (CFU/g)	0.04	1,000	Experts opinion[b]
r	4.40E-16	5.73E-05	5-95% percentiles[a]
M (g)	30	300	Experts opinion[b]
P (%)	1	60	Experts opinion[b]
FCC (%)	1.00E-10	3	Experts opinion[b]

Note: [a]International information (FAO/WHO, 2000) see Table III; [b]Food microbiologists of University of Chile

Table II. Minimum and maximum values given to some parameters of the study for the sensitivity test for both beef and poultry

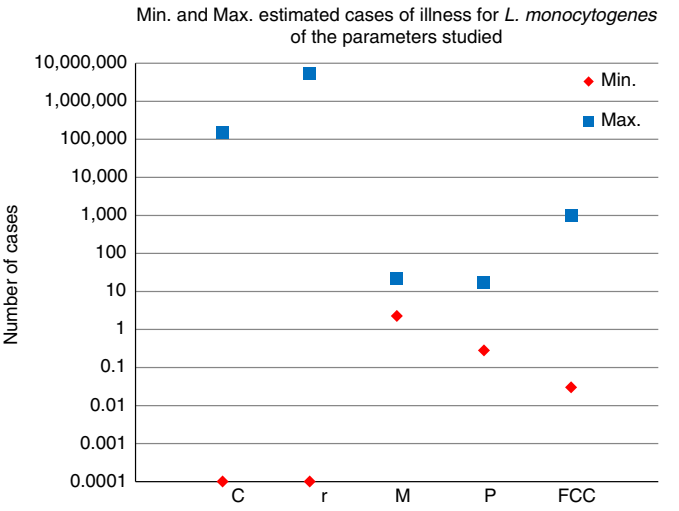


Figure 2.
Sensitivity analysis: minimum and maximum estimated number of cases of listeriosis for poultry consumption in the deterministic model based on Table II values

Dose-response models	*r*
FDA/USDA (2003) Butter[a]	1,02E-05
FDA/USDA (2003) Mex. Cheese[a]	3,70E-07
Lindqvist and Westöö (2000)	5,60E-10
Buchanan *et al.* (1997)	1,18E-10
FDA/USDA (2003) FDA-General[a]	8,50E-16
FDA/USDA (2003) FDA-Neonates[a]	5,00E-14
FDA/USDA (2003) FDA-Elderly[a]	8,40E-15
Notermans *et al.* (1998)	1,10E-06

Note: [a]Actualized in FDA/USDA (2003)

Table III.
Selected dose-response models of Table 6.1 of FAO/WHO (2000) used for the calculation of the dose- response *r* parameter

basic health indicators (Ministry of Health DEIS, 2010) , assuming a lethality of 10 percent for all illnesses. The total calculated immune-compromised people were 2.81 million.

Number of servings consumed/person/year and size (g) of the portion consumed per person (M). These parameters were calculated based on estimates of the Office of Agricultural Studies and Policies of Chile (ODEPA) on the apparent consumption of meat per person in 2011 (Chile Ministry of Agriculture, 2013). This corresponded to an estimated consumption of 22 kg/person/year of beef and 36 kg/person/year of poultry. Based on the beef consumption number we calculated that people consumed an average portion size of 153.1 g, 12 times a month. Based on the poultry consumption number we calculated that on average the same population consumes poultry meat 15 times a month with a portion size of 200 g.

Prevalence of L. monocytogenes in raw meat (P). The Chilean point estimate was based on a study of the Laboratory of Microbiology and Probiotics, INTA who found an occurrence of 37.5 percent (15/40 samples) in ground beef randomly purchased at supermarkets in the Metropolitan Region (MR) (Foerster *et al.*, 2012) and a prevalence of

54 percent (54/100 samples) in fresh chicken sampled in butcheries and supermarkets also in the MR (unpublished data).

Initial concentration (CFU/g) of L. monocytogenes in raw meat (C). We used in the deterministic model 0.1 CFU/g. It was based on the ILSI (2005) compilation data that concluded that the majority of foods have low concentrations of *L. monocytogenes*, usually between 0.04 and 0.1 CFU/g.

For the variability model we used data of the study of Inoue *et al.* (2000). We assumed and fit a lognormal distribution on these values by the @Risk 5.7 software (Palisade Corporations, Ithaca, NY), resulting in 2.15 (25.6) CFU/g for beef and 168.9 (6707.9) for poultry. For the uncertainty model, the mean value of the variability model was replaced with five values determined by expert opinion (0.04; 0.1; 1; 100; 1,000 CFU/g). In this case the option RiskSimtable of @Risk was chosen and five simulations were assessed.

Storage and probability of survival to inadequate cooking. Simulations were run with a combination of realistic temperatures and times of storage starting from the adequate storage of 4°C for 48 h (HHS, 2014) to 4°C for 72 h, 5, 6, 7, 8, 9 and 10 °C for 48 and 72 h.

Inadequate cooking simulations were run with a combination of temperatures and times starting from done meat > 65°C for 15 min (0 percent survival), to half-done meat: 60°C for 5 and 10 min, 55°C for 5 and 10 min and 50°C for 5 and 10 min. Raw meat gives 100 percent survival.

Portions (of raw meat) that contaminate the environment by cross-contamination (CX). It was based on a Netherlands study, where it was observed that the percentage of portions of raw chicken fillets that cross-contaminate into the environment (hands, cutting board, knife) was 94.5 percent (Nauta *et al.*, 2008).

Transfer factor (cross-contamination from the environment to the consumed product) (FCC). The *FCC* was considered in 2 steps: first, the pathogen's transfer from the raw meat to the environment ($\sqrt{FCC}$) and second, the pathogen's transfer from the environment to the RTE food ($\sqrt{FCC}$).The determinist model value was based on the data of the transfer study described above, where the average percentage of CFU's transferred from the environment to the product ready for consumption was 0.0456 percent (Nauta *et al.*, 2008). For the variability model the lognormal fit of the values of this study (Nauta and Christensen, 2011) was assumed for both beef and poultry models, resulting in 0.26744 (32.446) percent. The distribution was truncated so FCC < 1.

Consumption according to the food cooking level. Percentages of cooking categories were estimates from the authors as no national data were available. It is generally assumed that the chicken was consumed mostly well cooked, so the authors placed a small percentage for inadequate cooking (0.2 percent). In the case of beef the authors took a small percentage (0.5 percent) of raw consumption that includes the possibility of tartar or *filet americain* consumption, and a rate of 13.6 percent for inadequate cooking. This value was based on a Chilean study where 23 percent of people prefer to consume ground beef (5 kg/person/year) (Chile ODEPA, 2007). Assuming that all this meat is consumed as hamburgers and that Chilean people have the same consumption pattern as US people: 60 percent prefer to eat half-done hamburgers at home (Cassin *et al.*, 1998), then 3 kg of meat are consumed with an inadequate temperature of cooking, corresponding to 13.6 percent of total beef consumed.

Dose-response. In the determinist model, the r value was calculated based on the geometric mean of listeriosis cases based on international studies summarized in Table III (part of the Table 6.1 of the FAO/WHO, 2000 study). The r value used in the

model was 1.330×10^{-10}. For the uncertainty model, the r deterministic value was replaced with 5-95 percent percentiles of this international data that were assumed and fitted to a lognormal distribution by the @Risk 5.7 software. The option RiskSimtable of @Risk was chosen and ten simulations were assessed.

Number of illness. It was calculated by the formulas addressed in Table I.

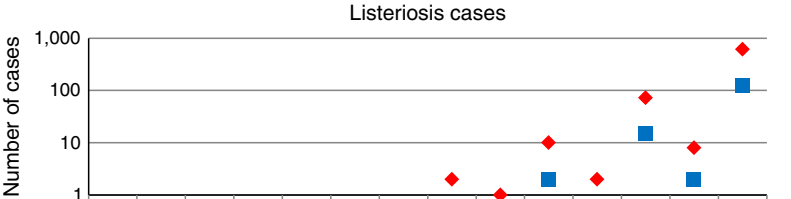
Excel and @risk calculations

The deterministic model, tables and graphs were constructed in Microsoft Excel XP (2010). The lognormal fits were made by the @Risk 5.7 software. In the probabilistic models the distributions were compared by Monte Carlo Analysis included in the @Risk 5.7 software, using 100,000 iterations. The total ingested dose and the probability of infection were calculated by the option RiskMean. This option gives the mean number of the values that result of each iteration. The output then, will be the mean number of listeriosis cases. In the uncertainty model, C or r values were replaced by introducing a simulation table called RiskSimtable of @Risk software. In the case of C five simulations were performed, and in the case of r ten simulations were performed both with 100,000 iterations.

Results

In the determinist storage model, growth of *L. monocytogenes* at 8°C for 72 h estimated ten and two listeriosis cases because of beef and poultry consumption, respectively, as shown in Figure 3(a). For better comparison (first combination with cases in both matrices) we took this temperature/time combination to run the other models. In these

(a)



Temperature and time of storage	4 °C 48 h	4 °C 72 h	5 °C 48 h	5 °C 72 h	6 °C 48 h	6 °C 72 h	7 °C 48 h	7 °C 72 h	8 °C 48 h	8 °C 72 h	9 °C 48 h	9 °C 72 h	10 °C 48 h	10 °C 72 h
Beef consumption	0	0	0	0	0	0	0	2	1	10	2	73	8	616
Poultry consumption	0	0	0	0	0	0	0	0	0	2	0	15	2	123

(b)

Temperature and time cooking	65°C 15min	60°C 10 min	60°C 5 min	55°C 10 min	55°C 5 min	50°C 10 min	50°C 5 min
Beef consumption	10	11	23	90	154	229	256
Poultry consumption	2	2	2	4	6	9	10

Figure 3.
Estimated listeriosis cases for poultry and beef consumption calculated with the deterministic model with a) different temperatures (°C) and times (h) of storage (at 60°C for 10 min cooking), and b) different temperatures (°C) and times (min) of cooking (storage parameter of 72 h at 8 °C)

calculations the percentage of *L. monocytogenes* survival due to inadequate cooking was set in 60°C for 10 min. The numbers of cases as a function of the survival of the pathogen due to inadequate cooking are shown in Figure 3(b). The adequate cooking temperature and time calculated with the *D*/*z* thermal inactivation model was 65°C for 15 min (0 percent survival). Half-done meat 60°C for 10 min gave 0.04 percent survival, 60°C for 5 min gave 2 percent survival, 55°C for 10 min gave 22 percent survival, 55°C for 5 min gave 50 percent survival, 50°C for 10 min gave 75 percent survival and 50°C for 5 min gave 86 percent survival. For example, listeriosis cases estimated for beef consumption with a recommended refrigeration (4°C for two days) are 0, increased to 11 in case of a storage of 8°C for three days, and rises to 651 cases if the refrigerator temperature is 10°C. In this case if there is also inadequate cooking (55°C for 5 min), estimated cases of listeriosis increased to 9,639 people. In the case of beef, most cases estimated were caused by half-done and raw beef consumption with cross-contamination. In poultry, the majority of cases estimated were caused by adequately cooked meat consumption with the presence of cross-contamination.

The mean numbers of listeriosis cases estimated in the variability model were 322 and 7,546 for beef and poultry consumption, respectively. The simulations were made at storage of 8°C for 72 h and cooking values of 60°C for 10 min. The estimated numbers of cases due to beef consumption were for approximately 55 percent due to raw meat, 33 percent from properly cooked meat and 8 percent from improperly cooked meat consumption, all with the presence of cross-contamination, and about 3 percent of cases from raw meat consumption without cross-contamination. In the case of poultry, results were similar to the deterministic model with approx. 99 percent of cases from properly cooked meat and 1 percent from inadequately cooked meat, both in presence of cross-contamination.

The listeriosis cases estimated by the model including the uncertainty of *r* and the model including the uncertainty of *C* are shown in Table IV. All simulations were made at storage of 8°C for 72 h and inadequate cooking of 60°C for 10 min.

The number of illness by *L. monocytogenes* estimated for beef and poultry consumption varied depending of the model (Table IV). The deterministic model gives higher estimates for beef consumption while the variability model gives higher estimates for poultry consumption. If the variability model includes the uncertainty of *C* the estimated cases were higher because of beef consumption. By contrast, in the variability model in addition with the uncertainty of *r*, the estimated cases were higher because of poultry consumption. In all cases, the *C* values were the responsible of the differences between models.

Discussion

The clear differences obtained in the models studied, confirms the importance of studies of variability and uncertainty despite that only some variables were chosen to perform these analysis because of lack of further information. Major differences were observed in the uncertainty results, especially among the extreme values of *r* and *C*. To reduce uncertainty, these two variables should be investigated with high priority. Bacterial enumeration studies have to be performed routinely in Chile in pathogen positive food. Better dose-response information should be obtained, but this is a difficult task, even from an international point of view (Lebert *et al.*, 2000; Rocourt *et al.*, 2003). Also, it seems urgent to generate national data about meat consumption, portion sizes, cross-contamination, ways of preparation and raw consumption, to increase the accuracy of the results and to assess the real importance of these variables in this model and future risk assessments.

Model	Storage	Cooking	Listeriosis cases Poultry	Beef
Determinist	4°C 48 h	65°C 15 min	0	0
$C = 0.1$ CFU/g	8°C 72 h	65°C 15 min	2	10
$FCC = 0.000456$	8°C 72 h	60°C 10 min	2	11
	8°C 72 h	55°C 5 min	6	154
Variability	8°C 72 h	60°C 10 min	7,546	322
C beef = lognorm(2.15;25.6) CFU/g				
C poultry = lognorm(168.9;6707.9) CFU/g				
FCC = lognorm(0.00267;0.324)				
Uncertainty r	8°C 72 h	60°C 10 min		
Percentile 5%			0	0
Percentile 15%			3	0
Percentile 25%			48	2
Percentile 35%			470	19
Percentile 45%			3,331	145
Percentile 55%			22,649	983
Percentile 65%			134,604	6,711
Percentile 75%			757,855	49,148
Percentile 85%			4,634,214	418,525
Percentile 95%			41,720,830	6,796,430
Uncertainty C	8°C 72 h	60°C 10 min		
0.04 CFU/g			0	5
0.1 CFU/g			1	12
1 CFU/g			9	131
100 CFU/g			3,961	15,105
1,000 CFU/g			54,921	142,842

Table IV. Summary of some estimated listeriosis cases for poultry and beef consumption

Several risk assessment models predicted that the best way to reduce listeriosis could be achieved by preventing growth of *L. monocytogenes* to high numbers (ILSI, 2005). Although there are no studies on domestic refrigerator temperatures and times of meat storage in Chile, it is speculated that the vast majority of people do not have a thermometer in their refrigerator, and therefore they are hardly calibrated to maintain a suitable temperature of 4° C (HHS, 2014). As for the storage time, although people read the label and product expiration date, new presentations of meat often have shelf lives longer than the two days recommended for fresh meat, for example vacuum-sealed meats. The growth model used in this study confirmed the importance of adequate home storage for the control of *L. monocytogenes* as shown in other studies done in RTE foods (FAO/WHO, 2000; ILSI, 2005). Results also suggest that cross-contamination is a major risk factor. This is supported by a Chilean study that evaluated various food chain stages and concluded that the greater safety loss was at the domestic stage due to poor handling and inadequate storage of food (Alerte *et al.*, 2011).

To prevent food safety loss due to cross-contamination, inadequate storage and/or cooking at home, it is essential to improve consumer education. Food companies must educate through means of an easy to understand labeling where according to the Chilean Food Sanitary Regulation, it must include the proper use of the product (Chile Ministry of Health, 1996). The government should conduct massive public education campaigns that focus on good hygiene behavior, manipulation of food and the correct interpretation of their label texts. Authorities should also promote the correct use of the refrigerator and food thermometers (FDA, 2012). It is also known that

people are more receptive to health authorities like doctors, nutritionists and nurses, so these professionals must be trained in information on listeriosis and other foodborne diseases to improve food safety behavior of the immune-compromised patients, the elderly and pregnant women (ILSI, 2005).

Listeriosis cases in Chile are on average 70 per year (four in 1,000,000 population). In that scenario, realistic results of the uncertainty study were made with a C of 0.04-1 CFU/g and a dose-response parameter r ranging 10^{-14}-10^{-10}, assuming that only a percentage of the total cases were produced by meat consumption. These results could limit the ranges used in future risk assessments of the pathogen and thus reduce the large uncertainties of the results due to poor information.

The overestimation seen in the results could be explained because of some important assumptions made in this study. First, the C values of the variability model were obtained from minced meat that can have more manipulation that whole meat. Also, the reference values used in the model of survival of *L. monocytogenes* by inadequate cooking correspond to the beef steak and chicken leg at 70°C (ICMSF, 1996). Because of the large number of products included in the model (ground meat to whole turkey), it was difficult to correctly interpret the results. Ideally models should limit the studied matrices to increase the accuracy of the final result. Further, this study did not consider the strain virulence and the effect of antagonistic flora in raw meat. In specific conditions *L. monocytogenes* did not compete well in meat environments contaminated with spoilage organisms including *Pseudomonas* and *Lactobacillus* (Buchanan and Bagi, 1999; Lebert *et al*., 2000). Also, the exponential model is a conservative model, which assumes that all organisms have the same probability r to cause infection. This model was chosen for its simplicity and also because the model output in terms of numbers of cases is closer to reality compared with other dose-response models. The exponential model was used by Buchanan *et al.* (1997) and Lindqvist and Westöö (2000) to estimate the risk of *L. monocytogenes* in smoked fish, and was also used in outbreaks studies associated with butter and Mexican-style soft cheese (FDA/USDA, 2003). Lindqvist and Westöö (2000) showed that the exponential model had more realistic results than the Weibull-Gamma model.

This is the first QMRA reported from Chile known to the authors. Although high uncertainties did not allow us to give a definitive answer whether beef or poultry can be included as an important source of listeriosis, this matrix cannot be eliminated as a cause of the disease. No massive food safety educational campaigns for consumers have been made for prevent the inadequate storage, cooking and handling of raw meat in Chile. Ready to sell meats must be studied in listeriosis cases where the epidemiological strain cannot be associated to a RTE food. The lack of information was the major limitation of the model, so the generation of useful data has to be a priority in Chile for developing less uncertain risk assessments in the future.

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