



Quantitative microbial risk assessment for *Escherichia coli* O157:H7 in Mutton in Qatar: an example of application of One Health approach

Hussni O. Mohammed¹, Kenlyn Peter¹, Ahmed Salem², Sanjay Doiphode³, Ali Sultan⁴

¹Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY, USA.

²Department of Animal Resources, Ministry of Environment, Doha, Qatar.

³Department of Medical, Hamad Medical Corporation, Doha, Qatar.

⁴Department of Medical, Weill Cornell Medical College-Qatar, Doha, Qatar.

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ABSTRACT

The objectives of the study were to evaluate the risk of illness from the consumption of Mutton contaminated with *Escherichia coli* O157:H7 in Qatar and to highlight intervention points that would contribute to mitigating its associated risk. The quantitative risk assessment (QRA) methodology was employed to address this objective. Our approach consisted of a combination of deterministic and stochastic approaches. Data on the probability of *E. coli* O157:H7 in animals, animal products, retail, and humans were obtained through repeat cross-sectional studies. Estimates of the adverse health effects were computed using risk characterization which integrated data on hazard characterization and exposure assessment, including dose-response models. The probability of illness for a healthy female from the consumption of mutton contaminated with *E. coli* O157:H7 eating at a restaurant ranged from 7×10^{-3} to 28×10^{-2} depending on the amount of food consumed. However, the risk for the same female eating at home is less (5×10^{-3} to 24×10^{-2}). The estimates of illness are three times higher for immunocompromised females exposed either at a restaurant or at home. The risk of illness due to this pathogen could be significantly reduced for either gender under different scenarios by increasing the efficacy of roasting the mutton before consumption.

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1. Introduction

One of the main diseases that impact the progress in maintaining and promoting health in populations around the world is foodborne illness (1).

*Corresponding author. Tel.: +989142362213

E-mail address: hussnimohammed@gmail.com

The Centers for Disease Control and Prevention (CDC) estimates that 48 million people become ill due to foodborne diseases each year in the US alone, 128,000 infections result in hospitalization with 3,000 infections resulting in death (1).



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The World Health Organization (WHO) estimates that unsafe food causes 600 million cases of foodborne diseases and 420,000 deaths worldwide per year (2). Thirty percent of foodborne deaths occur among children under 5 years of age. WHO estimated that 33 million years of healthy lives are lost due to eating unsafe food globally each year, and this number is likely an underestimation (2). The Foodborne Disease Burden Epidemiology Reference Group (FERG) with WHO is currently conducting an estimation of the worldwide burden of foodborne disease. In spite of the fact that foodborne infections are self-limited, estimates of the cost of illnesses range around the world, however, in the US the cost of infections due to *E. coli* STEC O157 alone was estimated at 300 million per year (3). Data on the cost of foodborne diseases is lacking in Qatar. The risk of foodborne pathogens has been exacerbated by the globalization of trade and ease of travel around the world. Qatar is one of the places where these two factors intersect. *E. coli* O157:H7 is among the most common pathogen detected in gastroenteric cases in Qatar (4). Furthermore, mutton (sheep and goat meat) is one of the most popular meats in Qatar where the total import reached a value of \$198 million in 2020 as can be found on <https://trendeconomy.com/data/h2/Qatar/0204>.

The high contamination rate among mutton samples that were collected at retail might exacerbate the risk of illness due to this pathogen (5). It has been reported that the prevalence of gastroenteritis among patients admitted to the hospital in Qatar exceeds 50% (6).

Generating knowledge on the pathway by which these threats enter the food chain and pose risk to humans will help in developing risk mitigation strategies. A common approach that has been used to inform producers and public health professionals, and to a lesser degree the public, is the use of the risk assessment approach (5). We carried out a study to identify factors that predispose to the risk of illness associated with the consumption of mutton contaminated with *E. coli* O157:H7 in Qatar and to identify intervention points that would help in extenuating its associated risk.

2. Material and methods

The study was carried out by a complementary team of researchers from the College of Veterinary Medicine at Cornell, Department of Animal Resources at Qatar, Hamad Medical Corporation (HMC) Hospital at Qatar, and Weil Cornell Medical College at Qatar. We employed the QRA methodology using a combination of deterministic and stochastic approaches to address the stated objectives (5). The QRA approach helps in identifying stages in the production system from farm to table that are likely to play a role in mitigating or exacerbating the risk of illness associated with the consumption of contaminated mutton with this pathogen. A scenario pathway model was developed delineating the process by which the targeted human population would be at risk of food poisoning from the consumption of contaminated mutton (Fig. 1).

The presented scenario is based on the framework proposed by the joint committee of the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (6). The proposed model consists of four steps: hazard identification, hazard characterization, exposure assessment, and risk characterization.

2.1. Hazard Identifications

The hazard of interest was *E. coli* O157:H7. Data on the likelihood of *E. coli* O157:H7 in animals, animal products, retail, and humans have been obtained through repeat cross-sectional studies in these populations in Qatar (7-11). The presence of the pathogens in samples collected during the repeated cross-sectional studies in these populations in Qatar was determined using a combination of bacteriological enrichment and real-time PCR detection (7).

2.2. Hazard characterization

E. coli O157:H7 is a serotype of *E. coli* that causes severe disease in humans and animals. It is different from other strains of *E. coli* because it produces a potent toxin that damages the lining of the intestinal wall in animals and humans causing bloody diarrhoea in young individuals other symptoms. It is also known as enterohemorrhagic *E. coli* infection. Outbreaks of *E. coli* O157:H7 have been associated with other types of foods such as spinach, lettuce, sprouts, unpasteurized milk, apple juice, apple cider, salami, and well water or surface water areas frequently visited by animals.

Outbreaks have also been traced to animals at petting zoos and day care centres. Although the pathogens could be found in faeces from healthy animals the shedding is intermittent.

2.3. Exposure Assessment

In the case of camel milk, human could contract the pathogens through the consumption of milk either at the farm or after milking and transfer of the milk to home. Offering fresh camel milk is considered a special treat. Healthy adults usually recover from infection with *E. coli* O157:H7 within a week. Young children and older adults have a greater risk of developing a life-threatening form of kidney failure.

2.4 . Risk Characterization

Estimates of the adverse health effects were obtained using risk characterization which integrated data on hazard characterization and exposure assessment, including dose-response models. A Monte Carlo Simulation of inputs in the model was performed using the @Risk software (Palisade Software, Newfield, NY, USA) and parameters were obtained using Latin Hypercube sampling in the model. Table 1 shows the different parameters used in the simulation at each step of the scenario and their hypothesized associated distribution. For the dose-response model, we used the single-hit exponential model (12). Sensitivity analyses were performed to capture the effect of uncertainty and variability of the different parameters used in the model on the predicted risk of illness due to the consumption of mutton contaminated with *E. coli* O157:H7.

3. Results

A total of 142 fecal samples from sheep, 300 swab samples from sheep carcasses, 289 swabs from mutton samples at retails, and 1092 fecal samples from human subjects were obtained. Fig. 3 shows the prevalence of *E. coli* O157:H7 in these samples as determined in our repeated cross-sectional studies.

Fig. 2 shows the prevalence of *E. coli* O157:H7 at different sources along the food supply chain as determined through repeated cross-sectional studies. The highest occurrence of the pathogens was among sheep at the farms and before the animals enter the food supply chain. Although the prevalence of this pathogen was highest at the source (farm) its likelihood dropped significantly further along the food supply chain. The average probability of the occurrence of the pathogen in samples at the abattoir was 2.5% (Fig. 2). The average value of contamination at retail was 5% (Fig. 2).

The probability of illness from the consumption of mutton was 3% among patients admitted to hospital with gastroenteritis symptoms. The probabilities of the organism at pre-harvest, abattoir, and retail were obtained from our previous studies. The probabilities and concentration at restaurants and at home were obtained from the literature. The dose-response relationship between exposure to the organism and the likelihood of the diseases for the two subpopulations (immunocompetent and immunocompromised) were obtained from the literature. Estimates of these values are shown in Table 1.

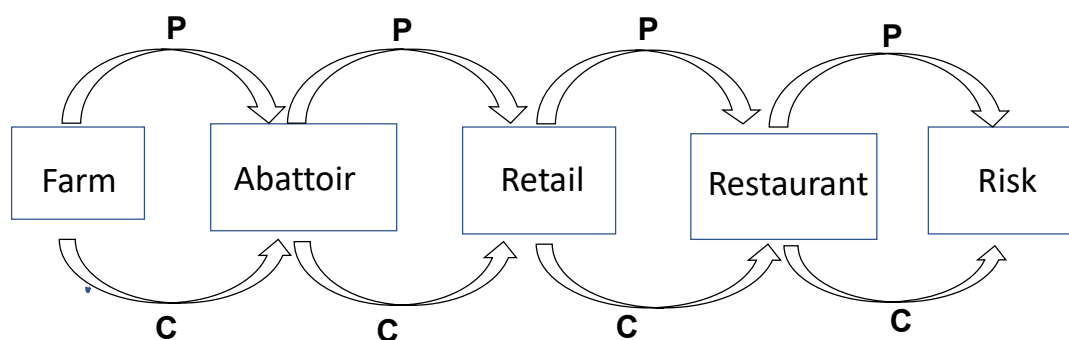
The probability of illness for a healthy female from the consumption of mutton contaminated with *E. coli* O157:H7 at a restaurant range from 7×10^{-3} to 28×10^{-2} depending on the amount of food consumed.

However, the risk for the same female eating at home is less (5×10^{-3} to 24×10^{-2}). The estimates of illness are three times higher for immunocompromised females exposed either at the restaurant or at home. We also evaluated the risk for healthy males exposed at restaurants and their risk was higher than for females under a similar scenario (13×10^{-3} to 44×10^{-2}). A similar trend of reduced risk was observed for men exposed at home (9×10^{-3} to 32×10^{-2}). The risk of illness due to this pathogen could be significantly reduced for either gender under different scenarios by increasing the efficacy of roasting of the mutton before consumption.

Fig. 3 shows the probability of illness for healthy and immunocompromised individuals at restaurants and at home. The probability of illness from the pathogen was higher eating at restaurants in comparison to eating at home. On average, immunocompromised individuals were twice more likely to become ill from the consumption of mutton contaminated with the pathogens in comparison to healthy (not immunocompromised) individuals (Fig. 3).

Table 1. Estimate of the parameters used in the scenario pathway, the hypothesized distribution, and the source of the estimate

Variable	Estimated parameter	Hypothesized distribution	Source of estimate
Probability of <i>E. coli</i> at the source	0.07	Beta(7+1, 100 - 7+1)	Mohammed et al., (10)
Concentration (cfu/g)	5	Log-normal (5, 5)	Mohammed et al., (10)
Probability on the carcass	0.45	Beta(24+1, 53 - (24+1))	Mohammed et al., (10)
Probability at retail (P_{rt})	0.73	Beta(67+1, 92 - (67+1))	Peters et al., (5)
Probability at restaurant (P_{rs})	0.25	Beta(38+1, 150 - (38+1))	
Concentration at restaurant (cfu/g/10)	571	Pert (114, 571, 4286)	
Concentration at home (cfu/g/10)	429	Pert (71, 429, 2571)	
Probability of illness	0.30		
Dose response model			
Susceptibility	0.005	Exponential -single hit	Tunnis et al., (12)

**Figure 1.** The hypothesized scenario pathway by which the target population would be put at risk of *E. coli* O157:H7

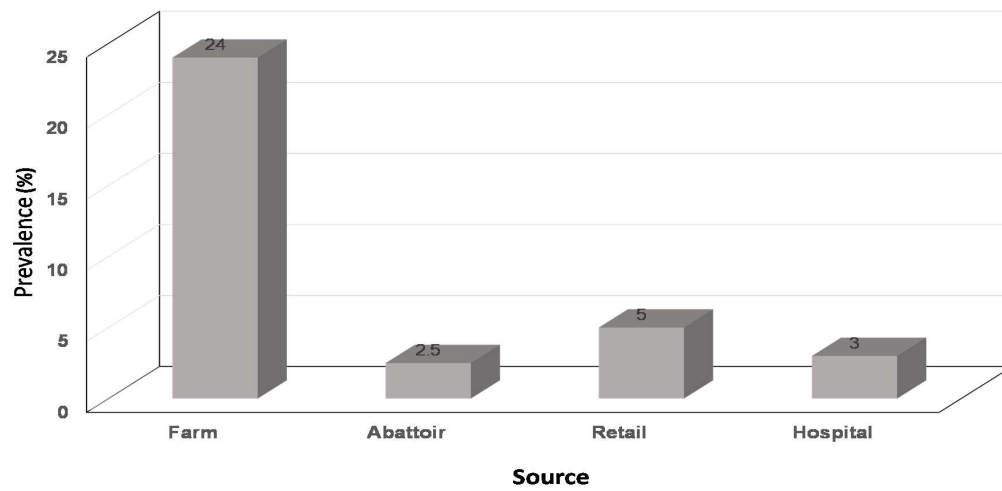


Figure 2. Prevalence of *E. coli* O157:H7 at different sources along the proposed scenario pathway

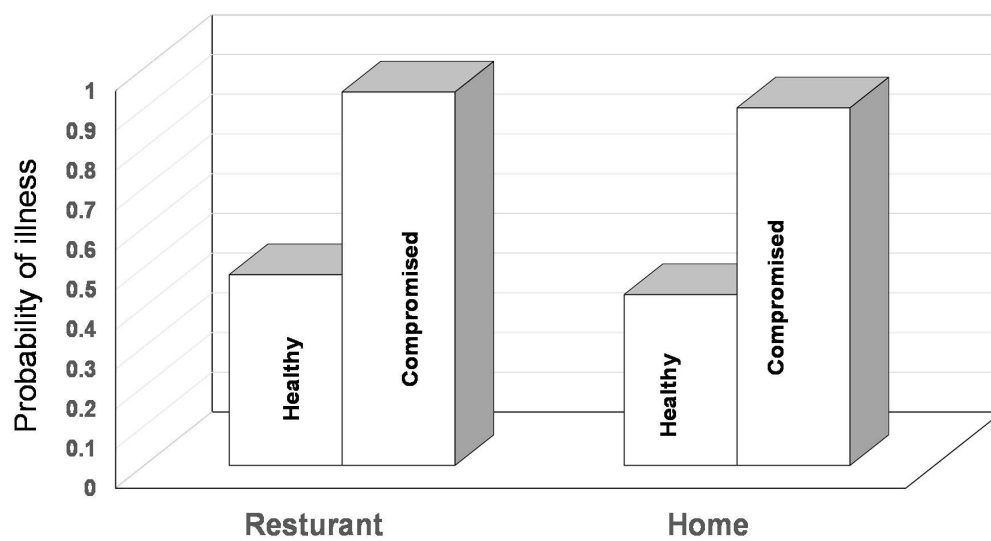


Figure 3. The probability of illness from eating mutton contaminated with *E. coli* O157:H7 in the two different scenarios: for healthy and immunocompromised individuals

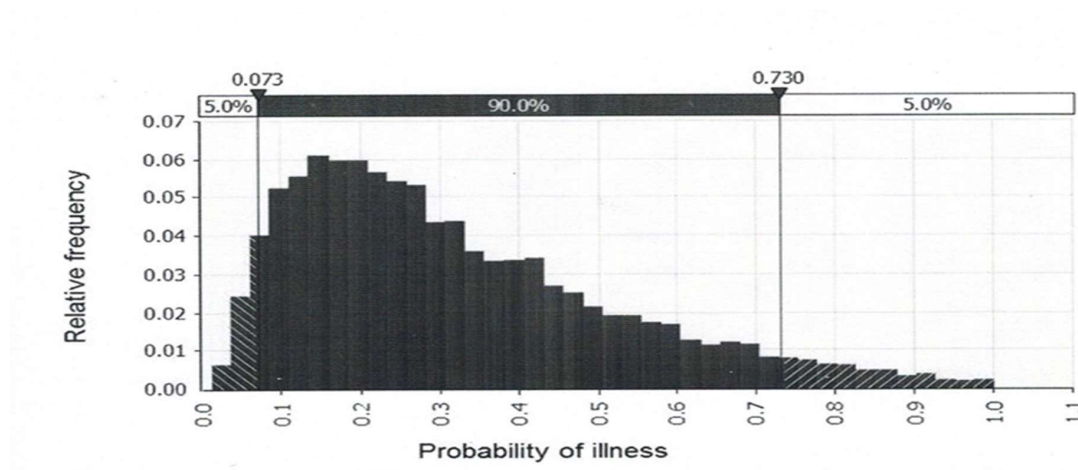


Figure 4. The relative frequency of the probability of illness at home from consuming mutton contaminated with *E. coli* O157:H7 as estimated with the proposed model

The distribution of the probability of illness was skewed to the left with the mode of 0.15 (Fig. 4). There was a 0.05% probability that the patients admitted to the hospital with gastroenteritis would have been infected with *E. coli* O157:H7 at the probability of 0.73 or higher (Fig. 4). Sensitivity analysis was performed to assess/identify the critical control points in the model that would impact the risk of illness. Ninety-five percent of the probability of illness in the model ranged between 0.073 to 0.73. Prevention of infection at the pre-harvest level would significantly reduce the probability of illness. Cooking the mutton well at the temperatures that would kill the pathogen also would reduce the risk of exposure to the pathogen, if no post-contamination occurs.

4. Discussion

Quantitative risk assessment analysis provides guidance for health professionals about the probability of potential adverse health effects to populations from exposure to harmful foodborne pathogens such as *E. coli* O157:H7. Such knowledge could be used to create intervention strategies to mitigate the cost associated with the adverse health impacts in a specific population. QRA models are used in different scenarios including the assessment of the risks associated with the consumption of food contaminated with pathogenic organisms (13-15).

The primary intent of this study was to inform public health professionals about the risk associated with a certain commodity so that cost-effective strategies could be implemented to ensure the wellbeing of the targeted population. In addition, the producer and the industry could use the knowledge gained from QRA to safeguard their product from pathogens that could threaten the quality of their product and the health of the consumer.

There has been a consensus among scientists working in the health of humans, animals and the environment to adopt a collaborative integrated effort to address the relevant challenges. The consensus has culminated into a concept of one health that encourages a collaborative, multispectral, and transdisciplinary approach with the goal of achieving optimal health outcomes recognizing the connection between people, animals, plants, and their shared environment (16, 17). Our manuscript is a demonstration of how such a complementary effort could be utilized.

We used a combination of deterministic approaches where we obtained estimates for the risk assessment model from observational studies on the targeted population and complemented these estimates with assumptions of the statistical distribution for these parameters. We believe that such an approach is likely to produce valid and reproducible estimates for the risk of illness since the estimates for the model were obtained from the same population. To our knowledge, this is one of the advantages of using the QRA in this study.

The rationale for the assumption of the beta distribution for the occurrence of *E. coli* O157:H7 at the source is because the majority of the mutton in the market is imported as frozen meat from different places around the world. Freezing is one of the food technologies that is known to have a destroying effect on foodborne pathogens (18). Furthermore, we believe the beta-distribution is one of the distributions that could account for such a rare event of the occurrence of *E. coli* O157:H7 in mutton.

The estimate of the prevalence of the pathogen among sheep and goats presented to the abattoir was obtained from our observational study carried out in the same population (10). The justification for the use of beta-distribution to capture the variability in the occurrence of the pathogen in mutton at the abattoir assumed that the contamination at the abattoir was rare because of the proper sanitary practices at the abattoir. Similarly, the probability of the pathogen at retail was obtained from our previous observational study and the distribution in the model was assumed to be relatively rare but higher than the abattoir because of the potential handling of the meat and storage at retail (5). We assumed that the distribution of *E. coli* O157:H7 in retail mutton samples is rarely based on our observational study (5). We collected a limited number of samples from retail and most of the mutton at retail is imported from different countries and is frozen. Also, those samples received thorough health inspection from the health authorities and there are no data from the countries of export on the presence of the pathogen.

Furthermore, we assumed that the freezing of mutton plays a major role in getting rid of pathogens that passed the inspection of health authorities (15,17).

Our model showed that on average there was a major reduction in the bacterial load of the pathogens from the original source as it moves along the food chain from the source to the abattoir. Observational studies showed a similar low occurrence in neighbouring countries (20). This reduction in the bacterial load could be attributed to the sanitary practices at the abattoir. There was a slight increase in the contamination rate in the model between the abattoir and retail. This could be attributed to the handling of the mutton at the retail and improper storage (21).

Our analysis showed that the probability of illness from the consumption of mutton contaminated with *E. coli* O157:H7 among gastroenteritis patients was significantly lower than what was reported in the literature on observational studies (5). The differences in the probability could be attributed to different factors in the target, one of which could be attributed to the nature of reporting this risk. For example, in one of the studies, the authors reported the percentage of the *E. coli* that was isolated from the gastroenteritis cases and the condition could be caused by other factors that were identified as *E. coli* O157:H7 among the *E. coli* isolates, wherein the analysis in this paper we reported the probability of the illness. Furthermore, the pathogen reported in the previous study was from all gastroenteritis cases irrespective of the sources of the pathogen.

Our analysis focused on the disease from the consumption of contaminated mutton; the previous study in the same population had not reported on the source of the pathogens among patients admitted to the hospital (5).

Several studies reported on the risk of illness associated with the consumption of ground beef contaminated with *E. coli* O157:H7 in different populations (13-15). Other studies focused on food other than ground beef (20-22) while none to our knowledge focused on mutton. Our study on the risk of mutton showed broad risk in the studied population. In addition, there are other factors that could predispose people to the risk of gastroenteritis or associated conditions (22). The age of the host had been identified as one of the factors (15). Another factor that we did not account for in our analysis was the dosage of bacteria susceptible hosts had been exposed to in the study. For the purpose of simplicity, we assumed the dose-response was based on the single hit model, for example, if the patient was exposed to one bacteria the patient would likely develop the illness (18).

5. Conclusion

This investigation demonstrated that collaboration among public health professionals that are entrusted with food safety (scientists, public servants at the food supply level, and human health services) shows the usefulness of the application of the One Health concept. To risk assessment in order to improve the wellbeing of societies.

The model provides a science-based justification for the awareness about the importance of the probability of adverse health effects and provides the foundation for risk managers and public health professionals and offers points of interventions to mitigate the risk of illness from exposure to *E. coli* O157:H7.

Conflict of interest

None of the authors has a conflict of interest.

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