Evidence for the benefits of food chain interventions on *E. coli* O157:H7/NM prevalence in retail ground beef and human disease incidence: A success story

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ABSTRACT

OBJECTIVES: Human infection with *Escherichia coli* O157:H7/NM has historically been associated with consumption of undercooked ground beef. The purpose of this paper is to investigate the correlation of the decline in *E. coli* O157:H7/NM infections in Canada with the introduction of control efforts in ground beef by industry.

METHODS: The human incidence of *E. coli* O157:H7/NM, prevalence in ground beef and interventions from 1996 to 2014 were analyzed. Pathogen prevalence data were obtained from federal government and industry surveillance and inspection/compliance programs. A survey of the largest ground beef producers in Canada was conducted to identify when interventions were implemented.

RESULTS: The incidence of *E. coli* O157:H7/NM infections in Canada declined from ~4 cases/100 000 to ~1 case/100 000 from 2000 to 2010. Verotoxigenic *Escherichia coli* (VTEC) prevalence in ground beef sold at retail declined from about 30% around the year 2000 to <2% since 2012. Other measures of the prevalence of *E. coli*, VTEC, and *E. coli* O157:H7/NM in beef and ground beef also declined. The number and types of interventions implemented in the major beef processing establishments in Canada increased from 1996 to 2016.

CONCLUSION: The observed decline in human illnesses and pathogen levels in relation to retail meats was associated with the introduction of control efforts by industry, federal and provincial/territorial governments, and the general population. Industry-led changes in beef processing along with the introduction of food safety policies, regulations, and public education have led to improved food safety in Canada.

KEY WORDS: *Escherichia coli*; food safety; beef

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Verotoxigenic *Escherichia coli* (VTEC, also known as Shiga toxin producing *E. coli* [STEC]) was first identified as a cause of food-borne outbreaks of hemorrhagic colitis in 1982¹ and of hemolytic uremic syndrome in 1983.² In the United States and Canada, the most commonly reported serotype in clinical cases is *E. coli* O157:H7/NM.^{3,4} *E. coli* O157:H7/NM is a pathogen with worldwide distribution,^{5–11} with infections more commonly reported in northern latitudes^{1,12} and in the summer.^{13–15} *E. coli* O157:H7/NM may be carried by a wide range of animals, with cattle and other domestic ruminants recognized as important reservoirs.^{16,17} Human infection can occur via consumption of contaminated food and beverages, recreational waters, and contact with humans or animals shedding the bacterium.^{11,18,19}

The term “hamburger disease” has been used in North America for *E. coli* O157:H7/NM infection, as a number of high-profile outbreaks associated with undercooked ground beef have occurred.¹⁹ While ground beef remains a potential source for exposure,¹ other foods, including salami, potato salad, apple cider, pork, and vegetable produce, are increasingly being identified as a source of exposure in Canada and internationally.^{14,20,21} In the US, the most common sources of *E. coli* O157:H7/NM infections are beef and leafy vegetables.²²

In Canada, *E. coli* O157:H7/NM and non-O157 infections became nationally notifiable in 1991 following incidence rates as high as 16.3 cases per 100 000 person-years.²³ The national incidence rate of *E. coli* O157:H7/NM infections was 2.8 cases per 100 000 person-years in 1997, increasing to about 4 per 100 000 person-years from 1999 to 2001 (excluding the 2000 waterborne outbreak in Walkerton, ON), and decreasing to 1.2 cases per 100 000 person-years in 2014.⁴

Canadian establishments that slaughter cattle are federally or provincially registered. There are 64 federally-registered

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establishments that slaughter beef and produce beef trims and 87 federally-registered establishments producing ground beef inspected by the Canadian Food Inspection Agency (CFIA). Production in federally-registered establishments represents 94% of the beef slaughtered in Canada (from 2007 to 2011),²⁴ with 6% produced at facilities subject to provincial inspection.²⁴ In 2010, production at three large plants accounted for almost 95% of the total volume of ground beef precursor material produced in federally-registered establishments.²⁵

Beef processing is done in seven stages in Canada (see Figure 1). A variety of physical and/or chemical interventions can be applied along the processing chain to control pathogens and have been implemented in Canadian beef processing plants.^{26,27} These interventions consist of either washing with hot water to remove pathogens or inactivating pathogens with chemical agents or hot water.^{24,27–32} Both chemical solutions and hot water treatments can be applied at different intensities (mist, spray, steam) and then removed by vacuuming.²⁴ Interventions can be administered at post-stunning, pre-evisceration and/or post-evisceration stages.²⁴

The CFIA works in close collaboration with industry, consumers, and other government departments to protect Canadians from preventable health risks associated with food and zoonotic diseases. It is responsible for enforcing food safety policies and standards set by Health Canada (HC) and verifies industry compliance with Canadian food safety standards. The CFIA routinely inspects federally-registered establishments producing raw ground beef and/or precursor materials (e.g., beef trims, boneless beef, head meat, tongue), intended for the production of ground beef. Beef trims are pieces of meat and/or fat that are obtained during carcass deboning that do not meet any meat cut labelling specifications.³³ Sampling and testing is one of many tools used to verify the operators' implementation of Hazard Analysis Critical Control Points (HACCP) programs and other controls for the prevention and control of *E. coli* O157:H7/NM.^{34,35} The CFIA deems satisfactory those samples in which *E. coli* O157:H7/NM is not detected and which contain less than 100 cells of generic *E. coli* per gram. When

samples exceed either of these thresholds, they are considered unsatisfactory and count towards the prevalence rate.

HC works to reduce population exposure to *E. coli* O157:H7/NM with stakeholders, including industry and its associations, federal/provincial/territorial governmental partners, academia and the Canadian public, to establish food safety standards, policies and regulations. It develops guidance documents and food safety standards, and reviews analytical methods based on these assessments.^{36–38} HC works with the CFIA and industry partners to review the efficacy of processing aids, food additives or other interventions on foods, and provides educational initiatives to inform consumers on a broad range of food safety topics.

The incidence of enteric disease in Canada is monitored at the national level by the Public Health Agency of Canada (PHAC). PHAC monitors and reports enteric illness data through the National Enteric Surveillance Program (NESP) and FoodNet Canada. NESP provides analysis and weekly reporting on the incidence of laboratory-confirmed cases of notifiable enteric disease cases in Canada. FoodNet Canada is an integrated enteric disease surveillance program, combining enhanced laboratory and epidemiological information on human cases of enteric disease with data from pathogen testing of retail foods,³⁹ surface water, and farm animals in sentinel communities. Human disease data are integrated with VTEC monitoring of fresh, retail ground beef, sampled weekly at retail in each site.

The purpose of this paper is to investigate whether the decline of the incidence of *E. coli* O157:H7/NM infections in Canada is correlated with the introduction of control efforts by industry, federal and provincial/territorial governments and the general population. Data from industry, the CFIA and PHAC are presented to describe these trends and associated interventions, including changes to food safety policies or regulations, public education, and changes in meat processing operations.

METHODS

To describe the changes introduced over time by the Canadian beef industry in an effort to reduce the prevalence of *E. coli* O157:H7/NM contamination in beef, the interventions at major Canadian beef processing plants, by targeted processing stage and beef parts, were summarized from 1996 to 2014 (Figure 2). The Canadian Meat Council (CMC) conducted an informal survey in 2014 of the largest Canadian beef producers, accounting for 80%–90% of ground beef production, to identify which interventions were implemented and when. The CMC also provided surveillance and verification data from its member processing plants. CMC data were analyzed to describe the rate of trim and ground beef samples that tested presumed positive or positive for *E. coli* O157:H7 and the total trim and ground beef destroyed or cooked (kg) in major Canadian beef establishments from 2008 to 2011.

Data on *E. coli* O157 in retail fresh ground beef were provided by FoodNet Canada. Each week, 12 samples of fresh ground beef are purchased for testing in the three sentinel communities in British Columbia, Alberta and Ontario.

Data from the meat processing industry is collected by the CFIA as part of their ongoing food safety inspection responsibilities. Data are available from the testing of ground beef and beef trim samples. Sampling of domestic raw ground beef was first

Figure 1. Seven stages of cattle processing, adapted from George Morris Centre³⁰

Figure 2. The accumulation of interventions at Canadian beef processing plants that process 80% of Canadian beef, by targeted processing stage and beef parts (data from Canadian Meat Council)

implemented in 2001/2002. Federally-registered establishments producing raw ground beef or raw ground veal intended for use as Finished Raw Ground Beef/Veal Products (FRGBP) are inspected by CFIA inspectors to verify the effectiveness of control measures for the prevention of *E. coli* O157 contamination. Each establishment is sampled 10 times per year. From a selected lot of ground beef/veal, the inspector randomly collects five subsamples (200 g each). Sampling is performed at the first grinding stage. The samples are analyzed for generic *E. coli* and *E. coli* O157/NM. The sampling of domestically produced beef trims was first implemented in March 2008. Federally-registered establishments producing beef trims and chucks intended for use in FRGBP are inspected by CFIA to verify the effectiveness of their control measures for *E. coli* O157. In 2014, the scope of sampling was expanded to include all precursor materials (PM) intended for use in FRGBP, including boneless beef, coarse ground beef, hearts, head meat, cheek meat, tongue roots, and weasand (oesophagus) meat. From a selected lot, the inspector implements the N60 method of sample collection to obtain 60 pieces of thinly sliced meat that are approximately 50 cm² each (e.g., 10 cm × 5 cm × 0.3 cm). The samples are analyzed for: generic *E. coli* (enumeration) and the presence of *E. coli* O157/NM.³³

Annual prevalence of generic *E. coli* (>10² cfu/g) and *E. coli* O157:H7/NM in ground beef and beef trim samples from Sampling and Testing Verification activities performed by the CFIA (2001–2014) in Canadian establishments were descriptively analyzed, with 95% confidence intervals.

E. coli O157:H7/NM incidence rates (NESP) (Figure 3) and FoodNet Canada data were analyzed to assess the trend in *E. coli* O157:H7/NM human disease and beef contamination over time (from 2001 to 2014) (Figure 6).

Significance of prevalence level differences by year was assessed with the Fisher's exact test using SAS 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

An increasing number of interventions to control bacterial pathogens were implemented at the major federally-registered

establishments in Canada since 1996 (Table 1 and Figure 2). In 1996, the first acid spray of carcasses in the chilling/prefabrication stage was implemented. From 1996 to 2002, interventions were introduced at the pre-evisceration, post-evisceration, and chilling/prefabrication stages, in multiple facilities. Additional carcass interventions and interventions targeting the hide and incision line (post-stunning), edible offal and other targeted meats and carcass areas (post-evisceration) were introduced from 2003 to 2007. Previously used intervention classes were more broadly adopted across the industry between 2008 and 2010 and interventions at the pre-packaging stage to cuts, trim, head, cheeks, and hanging tenders were also introduced. From 2011 to 2014, the use of interventions at the post-evisceration and prepackaging stages increased; new classes of interventions were not introduced during that time. Currently, 54 interventions to reduce bacterial contamination are in use by the major beef processors in Canada, 26 targeting beef trims/offal and 28 targeting beef carcasses.

From 2001/2002 to 2013/2014, the prevalence of generic *E. coli* counts at unsatisfactory levels in meat samples collected by CFIA (including ground beef and beef trim or trim component samples) decreased from 4.5% to 2.3% (Figure 3) ($p < 0.05$). From 2001/2002 to 2013/2014, the prevalence of *E. coli* O157:H7/NM in meat samples collected by CFIA (including ground beef and beef trim or trim component samples) decreased from 0.83% to 0.00% ($p < 0.01$).

E. coli O157:H7/NM prevalence data in trim or ground beef at processing plants are also collected independently by operators. From 2008 to 2011, the CMC documented that the proportion of trim and ground beef testing positive (or presumed positive) for *E. coli* O157:H7/NM declined from 0.58% in 2008 to 0.24% in 2009, then increased from 0.26% in 2010 to 0.41% in 2011 ($p < 0.01$) (Figure 4). When beef trims and/or finished ground beef products are reported positive for *E. coli* O157:H7/NM, industry must notify the regulatory authorities and take action to prevent public exposure to the contaminated product. The amount of trim or ground beef destroyed or diverted to cooking

Table 1. Number of interventions implemented at major Canadian beef processing establishments, by processing stage, target, intervention type, and year (Canadian Meat Council)

Processing stage and target	Intervention	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Post-stunning/skinning																				
Hide (including specific areas)	Water and acid sprays								1	1	1	1	2	2	2	2	2	2	3	5
Exposed area of carcass (round and midline)	Acid sprays																			1
Pre-evisceration																				
Carcass	Steam vacuum			2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Carcass	Sprays									2	3	3	3	3	3	3	3	3	2	2
Carcass	Water wash										1	1	1	1	1	1	1	2	2	3
Post-evisceration																				
Carcass	Steam/water wash/hot water		1	2	2	2	2	2	3	3	3	3	4	6	6	6	6	6	6	6
	pasteurization																			
Carcass	Steam vacuum													1	1	1	1	1	1	1
Carcass	Acid sprays									2	2	3	3	5	5	6	8	8	8	7
Head, heart, hanging tenders	Acid sprays									1	1	1	1	1	2	5	6	6	6	7
Heart and cheek meat																				
	Hot water																			1
	pasteurization																			
Held carcass	Acid spray																			1
Head	Acid spray																			1
Chilling/prefabrication																				
Carcass	Acid spray	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3
Carcass	Acid spray						1			1	1	1	1	2	2	2	3	3	4	4
Pre-packaging																				
Cuts, trim, head, cheeks, hanging tenders	Acid sprays													2	3	7	7	7	10	10
Total number of interventions		1	2	5	5	5	6	7	9	15	17	18	20	28	30	38	42	43	47	54

was highest in 2009 at 2 737 349 kg, decreasing to 1 476 572 kg in 2010 and 1 625 815 kg in 2011 (Figure 4).

FoodNet Canada has reported the annual prevalence of *E. coli* O157:H7/NM in retail ground beef since 2010. In 2009, FoodNet Canada adopted a more sensitive testing method for all VTEC serotypes, dramatically changing the reported prevalence by year (Figure 5)⁴⁰. Since 2010, the cumulative prevalence of *E. coli* O157:H7/NM was 0.1% with only 2 positive samples. VTEC prevalence in retail ground beef was <1.25% from 2005 to 2009, but a less sensitive method was used. Since 2009, prevalence rates on ground beef sold at retail in the three FoodNet Canada sites declined, from over 8% in 2009 to 4% in 2011 and <2% since 2012 ($p < 0.05$) (Figure 5). These prevalence values are substantially lower than the 15%–40% detected in ground beef using more sensitive methods for all VTEC between 1987 and 1991¹⁹ and the 33% detected in 2000.⁴⁶

Plotting the national incidence rates of *E. coli* O157:H7/NM infections over time as reported to the NESP, the incidence was 2.79 cases/100 000 in 1997, peaking at 5.6 cases/100 000 in 2000 (about 4 cases/100 000 with the exclusion of the Walkerton outbreak cases), decreasing ($p < 0.01$) until 2010. In 2014, the rate was 1.16 cases/100 000. These rates are plotted alongside the introduction of carcass and trim/offal interventions at major Canadian beef processing establishments (data gathered by the Canadian Meat Council) (Figure 6).

DISCUSSION

In Canada, since 2001 there has been a decreasing trend in human illness due to *E. coli* O157:H7/NM. During this period, there has also been a decreasing trend in the prevalence of *E. coli* O157:H7/NM in ground beef and beef trim. Canadian beef processing data also document a decreasing trend in the prevalence of *E. coli* O157:H7 in beef at the processing level from 2008 to 2011, as indicated by the rate of presumed positive and positive ground beef and trim samples and the quantity of product destroyed or diverted to cooking. The association between these temporal trends supports the hypothesis that the reduction in Canadian beef contamination with *E. coli* O157:H7/NM has contributed to a reduction in human exposure and disease.

The observed decline in *E. coli* O157:H7/NM contamination of beef in Canada is likely a result of a number of factors, including improved hygiene practices and control measures at beef processing plants. The possibility that the decrease in beef contamination has occurred as a result of lower carriage of *E. coli* O157:H7/NM in cattle can be excluded given that carriage rates in both dairy and beef cattle have remained relatively unchanged over the last 10 years.^{39,41} Further support for the role of changes to beef processing operations on a reduction in human illness comes from the observation that the prevalence of unsatisfactory generic *E. coli* numbers in regulatory beef samples has decreased from 2001 to 2014 and the rate of all VTEC has declined in FoodNet Canada retail beef samples since 2010.

It is clear that the last two decades have seen significant changes in the operations of the major Canadian beef processors, as indicated by the steady increase in the number of decontamination interventions implemented over this period. However, it is difficult to statistically determine which specific changes or interventions in processing operations have most significantly impacted the prevalence of *E. coli* O157:H7 in beef,

Figure 3. Annual prevalence of generic *E. coli* (>10² cfu/g) and *E. coli* O157:H7/NM in ground beef and beef trim samples from Sampling and Testing Verification activities performed by Canadian Food Inspection Agency, with 95% confidence intervals (numbers on the bars refer to the sample size) and trend lines

Figure 4. Rate of trim and ground beef presumed positive or positive for *E. coli* O157:H7 and the total trim and ground beef destroyed or cooked (kg) in major Canadian beef establishments by year (data from Canadian Meat Council)

and individual plant-level data which would support such analysis are not currently available. Research has been done to estimate the theoretical impact of a variety of individual and combined interventions during the processing of Canadian beef, from pre-harvest to consumption. It appears that as with most multi-factor public health issues, the most effective strategy for reducing the public health risk of *E. coli* O157:H7 includes interventions at several stages along the agri-food beef chain.⁴²

Other changes in industry practices have occurred during this same period, including the adoption of the Hazard Analysis Critical Control Point (HACCP) by processors, initially to meet US export requirements.^{43,44} HACCP requires assessment of the hazards at

critical points, the implementation of preventive measures at these points and monitoring effectiveness. Since 2004, HACCP has been mandated in Canada for all federally-registered establishments.^{44,45} Plant modernization and progressive improvements to machinery and equipment sanitation may also have contributed to improved hygiene.^{46,47} Contamination can occur further down the processing chain, and interventions that address contact surfaces, conveying equipment, worker's personal equipment, and staff training may also reduce contamination of the final product.^{28,30,48}

The role of regulatory or voluntary testing for *E. coli* O157:H7/NM of beef trim and ground beef production lots may also have

*Includes one sample positive for *E. coli* O157:H7

Figure 5. Prevalence of all VTEC serotypes (including O157:H7/NM) from FoodNet Canada retail ground beef sampling by year (2009a refers to the entire year of testing by method a; 2009b refers to a partial year of testing by method b (more sensitive) and 2010–2015 refer to annual prevalence by testing method b). *E. coli* O157:H7/NM was detected in one sample in years 2012 and 2014 (0.1% positive)

* spike in cases reported in 2000 resulted from the Walkerton, Ontario outbreak

Figure 6. Annual sum of interventions (carcass and trim/offal) in major Canadian beef processing establishments (Canadian Meat Council data) and incidence of *E. coli* O157 infections in Canada (National Enterics Surveillance Program data)

contributed to the observed reduction in illness. Production lots are withheld from distribution or further processing until presumptive testing results are available, and positive lots are destroyed or diverted to cooking. This process may directly improve product safety by filtering out contaminated meat from the production and distribution chain. It may also indirectly encourage improvements in hygiene, to reduce the financial costs associated with the diversion of positive lots.⁴⁹ If the observed reductions in beef contamination were solely a product of the filtering effect of testing, then it would be expected that

the frequency of retail ground beef samples positive for *E. coli* O157:H7/NM would have declined, while the prevalence of *E. coli* O157:H7/NM positive samples of ground beef and trim at the processor would have remained static as would have the prevalence of unsatisfactory generic *E. coli* counts.

The observed reduction in human illness is likely also a result of efforts to increase public health messaging, food safety training, package labelling and changes in food handling practices in both restaurants and in the home. Since the mid-1990s, federal, provincial and local public health organizations responsible for

consumer food safety education have focused on safe food handling. Examples include the “Food Safety Handle with Care” program developed with the Retail Council of Canada; BBQ safety cards developed with the CFIA and meat packers; and the “Be Food Safe” website, created by the Canadian Partnership For Food Safety Consumer Education.^{50–52}

With the reduction of *E. coli* O157:H7 in ground beef, other sources of exposure in Canada will likely become more important. The first Canadian reported outbreak from the consumption of pork occurred in 2011 in Ontario²¹ and since then there have been other reports of illness from pork contaminated with *E. coli* O157:H7/NM.⁵³

Food and human disease surveillance continues to evolve and a better understanding of *E. coli* O157:H7/NM transmission and infection will develop.⁵⁴ Continued surveillance is needed in Canada to monitor the prevalence of VTEC in retail ground beef and precursor products and the observed trend in reduction of illness caused by *E. coli* O157:H7/NM.

Future food safety research is required to evaluate on-farm interventions to reduce VTEC, including *E. coli* O157:H7/NM prevalence in cattle, in other commodities such as swine, and in surface water.¹⁵

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RÉSUMÉ

OBJECTIFS : Les infections humaines à *Escherichia coli* O157:H7/NM ont par le passé été associées à la consommation de bœuf haché insuffisamment cuit. L'objet de cet article est d'étudier la corrélation entre la baisse des infections à *E. coli* O157:H7/NM au Canada et l'introduction de mesures de contrôle du bœuf haché par l'industrie.

MÉTHODE : Nous avons analysé l'incidence d'*E. coli* O157:H7/NM chez les humains, sa prévalence dans le bœuf haché et les interventions menées entre 1996 et 2014. Nos données sur la prévalence des agents pathogènes ont été obtenues auprès du gouvernement fédéral et des programmes de surveillance et d'inspection ou de conformité de l'industrie. Nous avons sondé les plus grands producteurs de bœuf haché au Canada afin de déterminer le moment où les interventions ont été appliquées.

RÉSULTATS : L'incidence des infections à *E. coli* O157:H7/NM au Canada a baissé, passant de ~4 cas/100 000 à ~1 cas/100 000 entre 2000 et 2010. La prévalence d'*Escherichia coli* vérotoxigène (VTEC) dans le bœuf haché vendu au détail est passée d'environ 30 % vers l'an 2000 à <2 % depuis 2012. D'autres indicateurs de la prévalence d'*E. coli*, de VTEC et d'*E. coli* O157:H7/NM dans le bœuf et le bœuf haché ont aussi affiché des baisses. Le nombre et les types d'interventions appliquées par les grandes entreprises de transformation du bœuf au Canada ont augmenté entre 1996 et 2016.

CONCLUSION : La baisse observée des maladies humaines et des niveaux d'agents pathogènes en lien avec la viande vendue au détail était associée à l'introduction de mesures de contrôle par l'industrie, les gouvernements fédéral, provinciaux et territoriaux et la population générale. Les changements apportés par l'industrie à la transformation du bœuf, ainsi que l'introduction de politiques, de règlements et d'efforts de sensibilisation du public à la salubrité des aliments, ont entraîné une amélioration de la salubrité des aliments au Canada.

MOTS CLÉS : *Escherichia coli*; salubrité des aliments; bœuf