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Corresponding author:
Matt Hurst;
Email: matt.hurst@phac-aspc.gc.ca

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Estimated reduction in human salmonellosis incidence in Canada from a new government requirement to reduce *Salmonella* in frozen breaded chicken products

Suman Kanoatova, Matt Hurst, Brendan Dougherty, Danielle Dumoulin, Hailey M. Silver, Lisa O'Neill and Andrea Nesbitt

Public Health Agency of Canada, Centre for Foodborne, Environmental and Zoonotic Infectious Diseases, Foodborne Disease and Antimicrobial Resistance Surveillance Division, Guelph, Canada

Abstract

Nontyphoidal *Salmonella enterica* infections are a leading cause of enteric disease in Canada, most commonly associated with foodborne exposures. Raw frozen breaded chicken products (FBCP) have been implicated in 16 *Salmonella* outbreaks between 2017 and 2019. This study quantified the impact of the 1 April 2019 requirement by the Canadian Food Inspection Agency (CFIA) for manufacturers to reduce *Salmonella* in raw FBCP. An intervention study approach utilizing the pre–post intervention data with a comparison group methodology was used to: (1) estimate the reduction in FBCP *Salmonella* prevalence using retail meat FoodNet Canada data; (2) estimate the reduction in the human salmonellosis incidence rate using data from the Canadian National Enteric Surveillance Program; and (3) estimate the proportion of reported cases attributed to FBCP if the human exposure to *Salmonella* through FBCP was completely eliminated. The FBCP *Salmonella* prevalence decreased from 28% observed before 1 April 2019 to 2.9% after the requirement implementation. The CFIA requirement was estimated to reduce the human salmonellosis incidence rate by 23%. An estimated 26% of cases during the pre-intervention period can be attributed to FBCP. The CFIA requirement was successful at significantly reducing *Salmonella* prevalence in retail FBCP, and at reducing salmonellosis burden.

Introduction

Nontyphoidal *Salmonella enterica* (NTS) infections are a leading cause of domestically acquired acute gastrointestinal illness, responsible for an estimated 87510 food-related illnesses, 925 hospitalizations, and 17 deaths in Canada each year [1, 2]. Since these food-related illnesses account for an estimated 80% of the total NTS infections, identification of the most important food sources causing these infections is key in reducing the burden of foodborne salmonellosis [3, 4]. Several approaches to estimate the relative contribution of food sources to human enteric disease, known as source attribution of foodborne disease, have been employed, including epidemiological analysis of sporadic and outbreak-related cases, microbiological methods, comparative exposure assessment, expert elicitation, and intervention studies [5].

Epidemiological investigations into the increasing salmonellosis trend in Canada between 2000 and 2010 identified raw frozen breaded chicken products[1] (FBCP) as a risk factor for *Salmonella* infection [6–8]. These products were particularly concerning prior to April 2019, as they were sold predominantly raw but were partially fried and appeared cooked, resulting in improper cooking practices used by consumers [6, 9–11]. In 2018, an estimated 35% of Canadians considered raw FBCP to be precooked products that only require reheating [10]. A recent source attribution study, which used microbial subtyping methods, estimated that 12.9% of salmonellosis cases in Canada between 2010 and 2019 were attributed to raw FBCP [12].

The introduction of whole genome sequencing (WGS) for analysis of all clinical *Salmonella* isolates in Canada in May 2017 led to increased ability to detect and investigate *Salmonella* outbreaks [13]. There were 12 reported outbreaks consisting of 285 reported cases of *Salmonella* that were directly associated with raw FBCP exposure between April 2017 and April 2019. An additional four reported outbreaks comprised of 202 reported cases between April 2017 and July 2018 were associated with retail chicken exposure, which included raw FBCP [13]. As a result, starting in 2018, collective actions from the government and industry were undertaken, aimed at

[1]We use the term "frozen breaded chicken products" (FBCP) to refer to products that may be cooked or uncooked. When we refer to the uncooked/raw versions of the product, we use the term "raw FBCP", which is slightly different from previous publications that used "frozen raw breaded chicken products" (FRBCP).

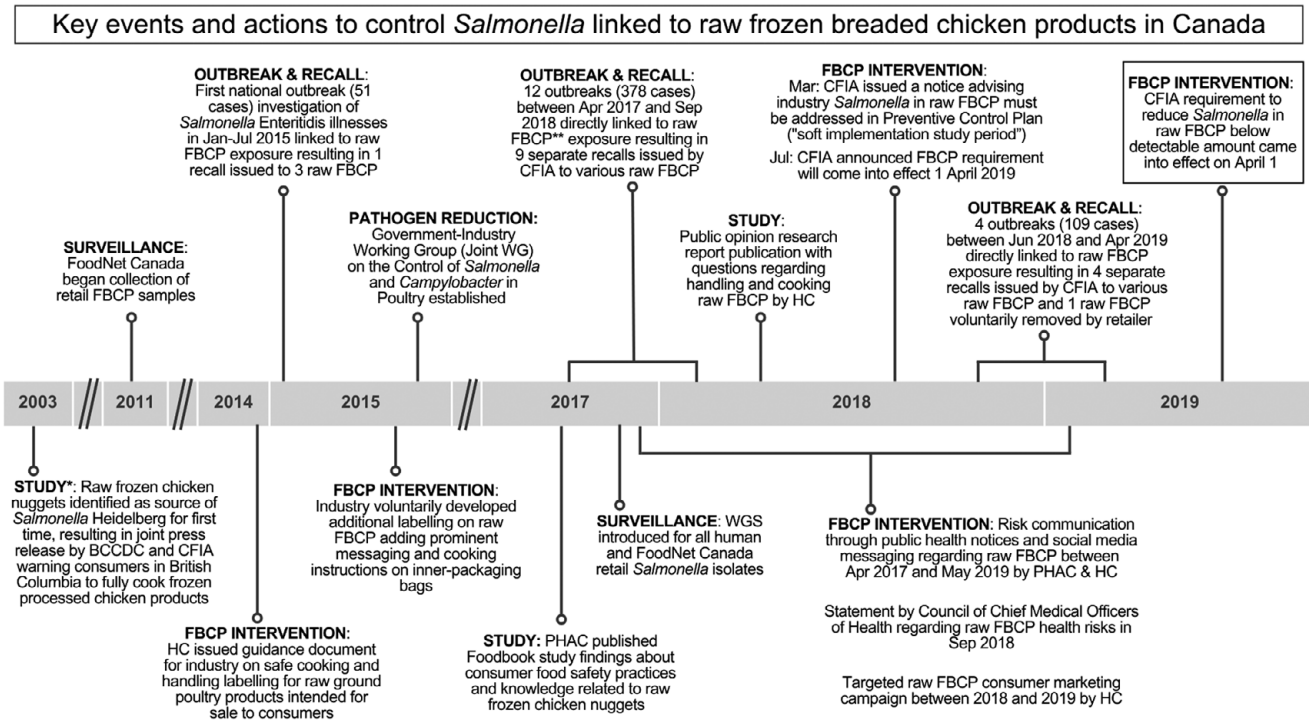

Figure 1. Timeline of key events and studies leading to the identification of raw frozen breaded chicken products as a risk factor for salmonellosis, as well as the government and industry collective actions and interventions undertaken to control foodborne FBCP-related *Salmonella* in Canada, 2003–2019. FBCP, frozen breaded chicken products; BCCDC, British Columbia Centre for Disease Control; CFIA, Canadian Food Inspection Agency; HC, Health Canada; PHAC, Public Health Agency of Canada; WGS, whole genome sequencing. *A British Columbia family cluster of *Salmonella* Heidelberg infections investigation in late February 2003 identified raw frozen processed chicken nuggets as the source of infection, which resulted in the press release by the BCCDC and CFIA in April 2003, and prompted a larger case–control study between January and April 2003 in British Columbia [6]. Subsequently, a national case–control study was undertaken in April 2003 by PHAC to identify risk factors of *S.* Heidelberg infections in Canada, and found that consumption of home-prepared chicken nuggets and/or strips increased the risk of illness by 4 times [7]. Finally, a prospective case–control study in Ontario found that processed chicken consumption increased *S. Enteritidis* infection risk by three times in 2011 [8]. The three publications describe the key studies that identified FBCP as a risk factor, and informed the targeted interventions prior to the 2019 CFIA requirement.
**There were eight outbreaks in which raw FBCP exposure was identified as the source of the outbreaks, and an additional four outbreaks in which raw retail chicken exposure, including raw FBCP, was identified as the source of the outbreaks.

reducing the burden of NTS infections attributable to raw FBCP [14]. - Figure 1 and Supplementary Table S1.1 present a timeline of these actions, as well as the key events that led to the identification of raw FBCP as a risk factor for salmonellosis.

Ultimately, in 2018 the Canadian Food Inspection Agency (CFIA) issued a notice to industry that they would need to implement control measures at the manufacturing/processing level to reduce *Salmonella* in FBCP to below a detectable amount beginning 1 April 2019, giving the industry 1 year to modify their FBCP processing procedures [15, 16]. The options for control measures prescribed by the new CFIA requirement[2] include: (1) inclusion of a cooking process validated to achieve reduction in *Salmonella*, resulting in a frozen ready-to-heat product; (2) implementation of a testing program to demonstrate no detectable *Salmonella*, (3) a combination of both; or (4) implementation of a *Salmonella* hold-and-test program for finished products [17]. Most FBCP manufacturers met the CFIA requirement by installing ovens to fully cook the product before it leaves the establishment [16, 18]. Products covered by this policy include non-intact (i.e. ground, comminuted, chopped, or formed) raw breaded par-fried chicken products (e.g. chicken nuggets and popcorn chicken) for retail only. Of note, this requirement does not apply to all FBCP, such as whole muscle intact raw breaded par-fried chicken products (e.g. chicken strips and chicken tenders) [17]. In addition, the requirement does not apply to raw breaded par-fried chicken products that are stuffed (e.g. chicken cordon bleu) [17], which are considered a separate category of FBCP, and thus are not within the scope of the present study.

The requirement by the CFIA in 2019 to reduce *Salmonella* in FBCP to below a detectable amount was an intervention that created a natural experiment in which a source of disease in an exposed population was largely removed. Exploiting this, our study used a pre–post comparison group methodology to investigate the impact of the 2019 CFIA requirement on *Salmonella* prevalence in retail FBCP, and the Canadian human salmonellosis incidence rate. In addition, this study estimated the proportion of salmonellosis cases attributable to FBCP *Salmonella* prevalence prior to the requirement implementation.

Methods

Data sources

We used data from two national Canadian enteric disease surveillance systems – the National Enteric Surveillance Program (NESP) and FoodNet Canada (FNC). NESP is a collaborative program between the Public Health Agency of Canada (PHAC) and the provincial public health laboratories. NESP monitors trends in select enteric pathogens across the ten Canadian provinces and

[2]The new CFIA requirement is also generically referred to as a policy or policy change throughout this paper.

three territories by conducting weekly analysis and reporting of enteric illness-causing pathogens [19]. FNC is a sentinel site surveillance system coordinated by PHAC in collaboration with provincial and local public health authorities. FNC collects information on four components – farm animals, retail foods, raw water sources, and human cases of enteric illness – in order to identify food and environmental sources for enteric illness [20].

Recognizing that many cases of *Salmonella* in people remain undetected, reported human *Salmonella* isolate data from NESP are nationally-representative, as NESP includes all laboratory confirmed cases in Canada. All reported *Salmonella* isolates were included from 26 May 2014 to 16 March 2020, and we refer to this as our overall study population.

A separate analysis was conducted using FNC human salmonellosis case data from three sentinel sites located in the provinces of Alberta (Alberta Health Services), British Columbia (Fraser Health), and Ontario (Middlesex-London Health Unit), reported between 1 January 2015 and 29 February 2020. Supplementary Appendix (SA) 2.1 contains details about the FNC human salmonellosis data.

Salmonella prevalence data from retail FBCP and intact raw chicken breast meat (CBM) samples were included from 26 May 2014 to 16 March 2020 from the three FNC sentinel sites in Alberta, British Columbia, and Ontario. The Quebec sentinel site was excluded, as it was officially established in July 2019, and did not have any pre-intervention data points. Retail products are randomly collected from large retail chain stores and independently owned stores on a weekly basis. The FBCP sampled were primarily uncooked products up to 2018. Some cooked FBCP were sampled in early 2019, with this proportion growing as the year progressed as a result of the CFIA requirement implementation. In addition, some whole muscle FBCP, which are not covered by the requirement, were included in the analysis as these products are part of the FBCP sampling by FNC. Since FBCP have a national distribution with only a handful of processing establishments that manufacture FBCP in Canada [21], it is reasonable to consider the *Salmonella* prevalence estimates from samples collected at the sentinel sites as nationally representative.

Statistics Canada provincial human population estimates for the period between 2013 and 2020 were used to calculate incidence rates [22].

Statistical analysis

We used a pre–post intervention comparison group methodology. As a robustness check, we also performed an interrupted time series (ITS) with a comparison group analysis, which has been used previously to estimate the impact of poultry-related *Salmonella* control programs [23, 24]. The ITS analysis methods are described in SA 2.4.

The human and nonhuman data were transformed into weekly time series and used in the ITS analysis. To maintain comparability, the same series were also used in the pre–post intervention analyses. Weekly salmonellosis case count data were converted to annualized incidence rates per 100000 population. The date of report to the provincial laboratory was used as the salmonellosis incidence date.

The chicken breast meat *Salmonella* prevalence was used as a qualitative comparison group for FBCP to assess the potential effect of other production-level interventions, since the majority of *Salmonella* serovars in the two types of products were the same. Missing *Salmonella* prevalence values were imputed by finding the mean for the two neighbouring weeks with values. There were 30 episodes of missing values of 1–4 weeks in duration, totalling 48 weeks for FBCP and CBM each. Cancelled retail sampling in those weeks was the most common cause of missing values.

To minimize seasonal confounding, seasonality in the salmonellosis incidence, FBCP and CBM *Salmonella* prevalence series was removed. The seasonally adjusted series were the residuals from a linear regression model of the unadjusted series and statistically significant dummy variables (from a possible 26, representing 2-week time intervals).[3] Further details can be found in SA 2.2.

The pre-intervention period was from 26 May 2014 to 31 March 2019. Linear regression was used to identify the beginning of the post-intervention period: this was where the *Salmonella* prevalence in FBCP samples had a predicted prevalence of zero (details in SA 2.3). The post-intervention period was from 14 October 2019 to 16 March 2020, which was when impacts from the COVID-19 pandemic began and FNC retail sampling paused. The period between 1 April 2019 and 13 October 2019 was the intervention period, when the application of the control measures prescribed by the CFIA requirement were driving the FBCP *Salmonella* prevalence downward. We refer to the official requirement deadline of 1 April 2019 as the hard implementation, and we use the term soft implementation to refer to the period when the CFIA released a notice to industry about the new FBCP control measures in March 2018, granting the industry a 12-month period to apply changes.

Comparison group

A comparison group, which was a subset of the overall study population, was generated by removing human cases that included *Salmonella* serovars detected in FNC FBCP samples. By removing the FBCP-related serovars, we attempted to create a comparison group in which the human incidence rate was not affected by the CFIA requirement targeted at FBCP. Therefore, the comparison group assessed and controlled for the potential influence of factors other than the FBCP policy that may have affected the overall human salmonellosis incidence.

Post-intervention reduction in FBCP Salmonella prevalence estimation

The unadjusted and seasonally adjusted reduction in FBCP *Salmonella* prevalence was calculated by subtracting the mean prevalence in the post-intervention period from the pre-intervention period mean prevalence, using the hard (1 April 2019) and soft (1 April 2018) implementation dates.

Pre- and post-intervention difference in salmonellosis incidence rate estimation

The mean salmonellosis incidence rate in the post-intervention period was subtracted from the mean rate in the pre-intervention period, which represented the reduction in the number of cases per 100000 population. Then, the difference-in-differences estimator was used to calculate the incremental effect of the FBCP intervention on salmonellosis incidence by subtracting the pre–post difference in the comparison group's incidence rates from the pre–post difference in the overall group. Separate calculations were developed for the hard and soft implementation dates, using both unadjusted and seasonally adjusted salmonellosis incidence rates. Example calculations are shown in SA 2.5.

[3] A sinusoidal approach using sin and cos functions did not fit the data as well.

Table 1. Unadjusted and seasonally adjusted *Salmonella* prevalence in retail samples of frozen breaded chicken products and chicken breast meat during the pre- and post-intervention periods, and the pre–post intervention differences using FoodNet Canada data, 2014–2020

	Mean *Salmonella* prevalence	Pre-intervention Unadj.	Pre-intervention Seas. adj.	Post-intervention Unadj.	Post-intervention Seas. adj.	Pre–post difference Unadj.	Pre–post difference Seas. adj.
		Prevalence per cent (95% CI)					
Hard impl.	Frozen breaded chicken products	28 (26, 30)	28 (26, 30)	2.9 (0.69, 5.1)	2.9 (0.69, 5.1)	25 (22, 28)	25 (23, 28)
	Chicken breast meat	21 (19, 23)	20 (18, 22)	23 (19, 28)	23 (19, 28)	−2.8 (−7.7, 2.1)	−3.3 (−8.1, 1.6)
Soft impl.	Frozen breaded chicken products	27 (25, 29)	27 (24, 28)	2.9 (0.69, 5.1)	2.9 (0.69, 5.1)	24 (21, 27)	24 (21, 27)
	Chicken breast meat	21 (19, 23)	22 (19, 24)	23 (19, 28)	23 (19, 28)	−2.2 (−7.2, 2.7)	−1.9 (−6.8, 3.1)

Unadj., unadjusted; Seas. adj., seasonally adjusted; 95% CI, 95% confidence interval; Hard impl., hard implementation – using 1 April 2019 as beginning of intervention period; Soft impl., soft implementation – using 1 April 2018 as beginning of intervention period.

Policy impact and source attribution

We used an intervention study approach for source attribution, as defined by Pires et al. [4]. The impact of the CFIA policy was the difference-in-differences estimate using the hard implementation period expressed as a per cent of the seasonally adjusted incidence rate in the pre-intervention period. The approach for the source attribution calculation was similar. Here, however, we estimated the unit reduction in salmonellosis incidence rate (from the policy impact analysis) per percentage point drop in FBCP *Salmonella* prevalence that was observed after the requirement implementation. We then extrapolated the source attribution percentage for the scenario where exposure to *Salmonella* through FBCP is completely removed by substituting 0% prevalence, instead of the post-intervention FBCP *Salmonella* prevalence that was observed in our study (equation used in these calculations and example calculations are included in SA 2.6).

Range estimates were reported using 95% confidence intervals (CI). All analyses were performed using STATA BE for Windows, version 17 (Stata Corporation, College Station, TX, USA).

Results

The FBCP *Salmonella* prevalence using the hard implementation period dropped from 28%, CI (26%, 30%) in the pre-intervention period to 2.9%, CI (0.69%, 5.1%) in the post-intervention period, resulting in a 25, CI (22, 28) percentage point *Salmonella* prevalence reduction (Table 1, Figure 2a). The CBM *Salmonella* prevalence did not change significantly (Table 1).

An estimated reduction of 4.7, CI (3.9, 5.6) cases per 100000 population was observed, after subtracting the small change in the comparison group, using the hard implementation date (Table 2 and Figure 2b). When the soft implementation date was used, the estimated reduction was 5.8, CI (5.0, 6.6) cases per 100000 population.

Policy impact and source attribution

The per cent drop in the salmonellosis incidence rate during the post-intervention period compared with the pre-intervention period was 23%, CI (19%, 27%) (Table 3). Using the scenario where exposure to *Salmonella* through FBCP is reduced to 0%, it was estimated that 26%, CI (20%, 31%) of salmonellosis cases in the pre-intervention period can be attributed to FBCP.

The analyses using ITS, as well as analyses with FNC human salmonellosis data found largely similar results, which are shown in SA 3.

Discussion

This study assessed the impact of the 2019 CFIA frozen breaded chicken products requirement on *Salmonella* prevalence in retail FBCP using FNC data, and the human salmonellosis incidence rate using data from the NESP, as well as estimated the proportion of cases attributable to FBCP exposure prior to the intervention. We found that the new CFIA requirement was successful at substantially reducing *Salmonella* in retail FBCP, and contributed to a significant reduction in the human salmonellosis incidence rate. To our knowledge, this is the first study that estimated source attribution percentages utilizing the intervention approach for food source attribution using national enteric surveillance data in Canada.

Policy impact

We observed a 25% point drop in *Salmonella* prevalence in the FNC retail FBCP samples following the CFIA requirement implementation. The presence of *Salmonella* in the post-intervention FBCP samples is largely due to the prevalence in products that are not currently covered by the new requirement, but are included in the FNC retail sampling activities, such as whole muscle FBCP. According to more recent FNC surveillance data of retail FBCP *Salmonella* prevalence, 3.7% of FBCP samples were *Salmonella*-positive between 2020 and 2022,[4] and represent FBCP that are currently not under the CFIA requirement [25]. The 2.9% *Salmonella* prevalence observed in FNC samples during the post-intervention period may also be due to the long freezer life of FBCP, as these products may remain in retail store freezers for a long time [26]. This "freezer effect" also explains the national outbreak linked to FBCP that was identified after 1 April 2019, as the recalled product associated with this outbreak was sold nationally until 1 May 2019, and consumers may still have had it in their home freezer in May 2019 or beyond [27]. Although other upstream interventions in the chicken industry (e.g. vaccination) may have had an impact on *Salmonella* in chicken throughout the study period, we did not observe a significant reduction in the raw chicken breast meat *Salmonella* prevalence during the same period that the FBCP prevalence decreased significantly in the post-intervention period. This suggests that it is unlikely that other upstream interventions in the chicken industry could explain the

[4]We did not include data past March 2020 in the analysis of the current study due to the long pause in FNC retail sample collection resulting from the COVID-19 pandemic.

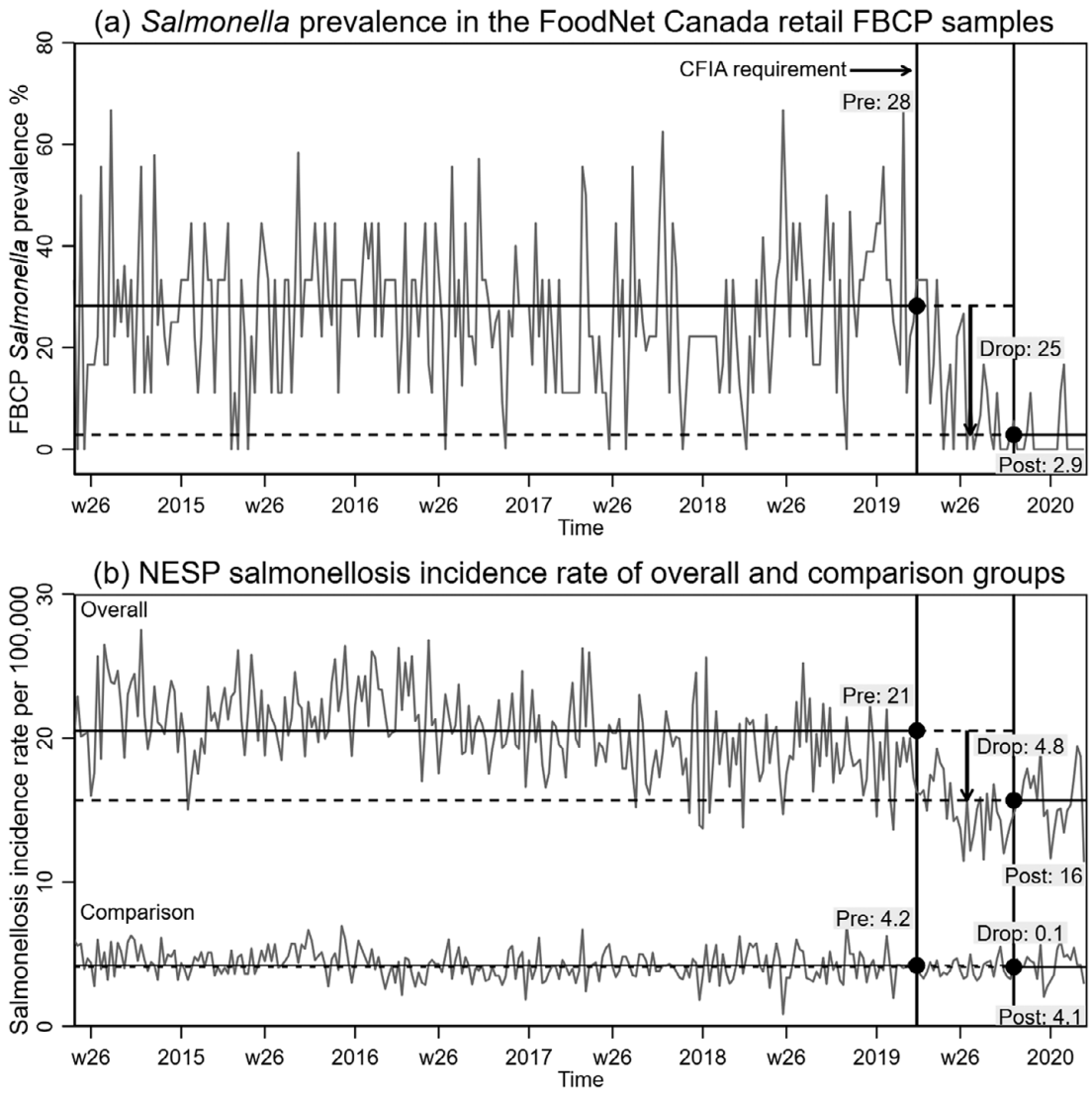

Figure 2. Seasonally adjusted frozen breaded chicken products *Salmonella* prevalence (panel a), and human salmonellosis incidence rate (panel b) during the pre- and post-intervention periods. FBCP, frozen breaded chicken products; CFIA, Canadian Food Inspection Agency; NESP, National Enteric Surveillance Program; w26, week 26; ● indicates the mean value at the specified time point. Panel b: Difference-in-differences estimated by subtracting drop in comparison group incidence (0.1) from the drop in overall group incidence (4.8).

Table 2. Unadjusted and seasonally adjusted human salmonellosis incidence rates of the overall and comparison groups during the pre- and post-intervention periods, and the pre–post intervention differences using National Enteric Surveillance Program data, 2014–2020

	Mean salmonellosis incidence rate	Pre-intervention Unadj.	Pre-intervention Seas. adj.	Post-intervention Unadj.	Post-intervention Seas. adj.	Pre–post difference Unadj.	Pre–post difference Seas. adj.	D–I–D Unadj.	D–I–D Seas adj.
		Cases per 100000 population (95% CI)							
Hard impl.	Overall group	20 (19, 20)	21 (20, 21)	13 (12, 14)	16 (15, 17)	6.9 (5.8, 8.1)	4.8 (3.9, 5.8)	6.7 (5.9, 7.6)	4.7 (3.9, 5.6)
	Comparison group	4.3 (4.1, 4.4)	4.2 (4.1, 4.3)	4.0 (3.6, 4.5)	4.1 (3.7, 4.6)	0.23 (−0.22, 0.68)	0.10 (−0.36, 0.56)		
Soft impl.	Overall group	20 (20, 21)	20 (20, 20)	13 (12, 14)	14 (13, 15)	7.3 (6.2, 8.5)	5.9 (4.9, 6.8)	7.1 (6.2, 8.0)	5.8 (5.0, 6.6)
	Comparison group	4.3 (4.1, 4.4)	4.3 (4.1, 4.4)	4.0 (3.6, 4.5)	4.2 (3.8, 4.6)	0.25 (−0.20, 0.71)	0.060 (−0.40, 0.52)		

Unadj., unadjusted; Seas. adj., seasonally adjusted; D-I-D, difference-in-differences; 95% CI, 95% confidence interval; Hard impl., Hard implementation – using 1 April 2019 as beginning of intervention period; Soft impl., soft implementation – using 1 April 2018 as beginning of intervention period.

Table 3. Frozen breaded chicken products policy impact and food source attribution of human salmonellosis percentages using National Enteric Surveillance Program and FoodNet Canada data, 2014–2020

	Policy impact/source attribution	Per cent (95% CI)
Hard impl.	Policy impact. Reduction in human salmonellosis incidence rate attributable to the drop in FBCP *Salmonella* prevalence after new FBCP requirement	23 (19, 27)
	Source attribution. Extrapolated reduction in human salmonellosis incidence rate if FBCP exposure completely removed	26 (20, 31)
Soft impl.	Policy impact. Reduction in human salmonellosis incidence rate attributable to the drop in FBCP *Salmonella* prevalence after new FBCP requirement	29 (25, 33)
	Source attribution. Extrapolated reduction in human salmonellosis incidence rate if FBCP exposure completely removed	33 (27, 38)

FBCP, frozen breaded chicken products; Hard impl., hard implementation – using 1 April 2019 as beginning of intervention period; Soft impl., soft implementation – using 1 April 2018 as beginning of intervention period; 95% CI, 95% confidence interval.

significant drop in FBCP *Salmonella* prevalence observed in our study.

The CFIA requirement was estimated to reduce the salmonellosis incidence rate by 23% using the pre–post intervention comparison group method. Our approach for policy impact estimation does require the assumption that the change in the human salmonellosis incidence rate was due to the change in the *Salmonella* prevalence in FBCP that resulted from the policy intervention. However, there was very little change in the comparison group salmonellosis incidence rate, which suggests that other concurrent factors were not substantively significant, and provides support that our assumption is reasonable. The addition of the comparison group enhanced our confidence that we were isolating the effect of the CFIA requirement on the incidence rate. We found a similar policy impact when using the interrupted time series (ITS) methodology that adjusted for a temporal trend, albeit small, in the incidence rate. Thus, with the ITS, we were able to further eliminate another explanation for the change in the outcome, which provided additional confidence that we had isolated the effect of the CFIA requirement.

However, there is still a possibility that other factors may have affected only those serovars that were found in FBCP which were excluded from the comparison group. Any remaining factors that could contribute to a reduction in raw chicken breast meat *Salmonella* prevalence, such as upstream poultry interventions, can be ruled out since the prevalence of *Salmonella* on raw CBM was stable. This strengthens the argument that the reduction in FBCP *Salmonella* prevalence from the CFIA requirement was driving the reduction in salmonellosis incidence.

Our estimate of 23% reduction in nontyphoidal *Salmonella* incidence is consistent with a previous burden of illness study which estimated a 19.6% reduction in NTS incidence rate in 2019 compared with 2014–2018 [14]. Our estimate is slightly higher due to different time periods being compared, as well as the addition of a comparison group.

When the soft implementation date was used, the estimated reduction in salmonellosis incidence rate due to the CFIA requirement was 29%. This larger effect may be due to the CFIA granting the industry a 12-month implementation period, which potentially lead to early adoption of control measures throughout this period. This period also captured the effects of the collective actions by the government and industry being implemented to improve FBCP safe cooking practices through risk communication messaging and consumer awareness-raising interventions regarding health risks associated with raw FBCP, and FBCP recalls which are shown in Figure 1 and described in detail elsewhere [28, 14]. Although these interventions likely had an effect, we believe that the CFIA requirement had the greatest contribution to the observed reduction in salmonellosis, because salmonellosis cases and outbreaks associated with exposure to FBCP continued to be identified, despite the various interventions implemented throughout the pre-policy change period [13].

In addition, evidence suggests that the effectiveness of awareness-raising interventions in regard to raw FBCP handling is limited. For example, a study using survey data on consumer reactions to safe food handling instructions through labels on raw poultry products suggested that labelling had only limited influence on consumer practices [29]. More recently, the United States Department of Agriculture's Food Safety and Inspection Service conducted a meal preparation experiment that included an educational intervention which communicated that FBCP are not ready-to-eat and that the endpoint temperatures should be checked with a food thermometer [11]. It was found that even with proper labelling and cooking instructions, over a quarter of study participants who received the intervention did not understand that the products contained raw chicken meat [11]. Furthermore, although the par-fry process destroys surface pathogens and the majority of illnesses resulted from undercooking of raw FBCP, the risk of *Salmonella* transmission may still remain even with proper raw FBCP cooking as per label instructions, which may result from improper food safety practices, such as not handwashing before and after handling the raw product, and cross-contamination [28]. The introduction of *Salmonella* control measures at the manufacturing level with the implementation of the CFIA requirement reduces the risk of exposure at the consumer preparation level [21], as all products are regulated to have no detectable *Salmonella* present. This likely contributed to the policy's success. However, as there was an overlap between the earlier FBCP interventions and the soft implementation of the CFIA requirement, to be conservative, we consider the 23% to be an upper bound on the policy impact. It is also important to note that the CFIA requirement does not eliminate *Salmonella* exposure risk from these products completely since some FBCP are not covered by the requirement. Thus, consumers should still follow package directions where applicable, and cook chicken products fully to inactivate enteric pathogens like *Salmonella* to prevent illness [26].

Source attribution

Our study is one of the few that have utilized an intervention study approach for food source attribution. In Belgium, a similar methodology was used, employing a pre–post intervention analysis, to estimate the per cent decline in *Campylobacter* infections following the removal of all poultry products as a result of dioxin contamination in livestock feed [30]. We estimated that 26% of human salmonellosis cases prior to the CFIA requirement implementation were due to FBCP. However, since our methods cannot completely rule out other unobserved factors that may have contributed to the drop in cases associated with only chicken-specific serovars during the same time period, we propose 26% to be the upper bound of the true source attribution estimate. Previous Canadian source attribution work estimated that 12.9% of salmonellosis cases in the same

three FoodNet Canada sentinel sites were attributed to raw FBCP [12], which is consistent with our 26% source attribution estimate when considered as the upper bound. Future work may explore the use of a multivariate time series regression with FBCP *Salmonella* prevalence as the independent variable, as this may provide direct evidence of causal ordering between aetiological agent and reported illness, as well as a more accurate estimate of the true source attribution percentage.

Limitations

A limitation of this study is that the post-intervention period was shorter than the pre-intervention period due to the disruption in FNC retail sampling during the COVID-19 pandemic, and to avoid confounding due to the substantial drop in the reported human salmonellosis cases that resulted from the pandemic [31]. A longer post-intervention period would allow for the FBCP manufactured before the policy implementation to be fully removed from consideration, by being completely consumed or thrown out. In addition, it was not possible to exclude FBCP that are not covered by the CFIA requirement (e.g. whole muscle FBCP) from the analysis as these products are included in the FoodNet Canada FBCP sampling and cannot be easily differentiated. However, most of the product clearly must fall under the requirement given that the post-intervention prevalence of *Salmonella* was very low, which largely mitigates this limitation. Furthermore, our methods and the ecological nature of the data cannot exclude all potential time-varying confounders which were not captured in the comparison group or do not form part of the long-term trend. We were not able to assess all external, concurrent factors that may have influenced salmonellosis incidence, such as changes in consumer behaviour in the safe preparation of FBCP and potential declines in poultry consumption. Finally, the ability to use the chicken breast meat *Salmonella* prevalence as a qualitative control group for the FBCP prevalence relies on the upstream poultry interventions for the chicken breast meat sources to be the same as the sources of the FBCP chicken meat. Considering that spent hen meat can be used in the manufacturing of FBCP, while broiler chicken meat is used for production of retail chicken breast meat, there may be differences in the rearing, slaughter, and processing associated with these two sources, potentially leading to differences in the overall prevalence of *Salmonella* in the two chicken products.

Conclusions

Our study estimated the impact of a targeted food safety policy intervention which may further guide knowledge users and policymakers to make evidence-informed decisions. The study estimated that the CFIA's FBCP requirement implementation was successful at reducing the pre-intervention salmonellosis burden associated with FBCP by 23%, with other FBCP interventions potentially contributing to this reduction. We estimated that 26% of the pre-intervention salmonellosis cases can be attributed to FBCP, if product *Salmonella* prevalence dropped to 0%. The current study explored the short-term impact of the CFIA requirement, and thus future studies are needed to evaluate the long-term effects of the policy on the human salmonellosis incidence in Canada.

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Data availability statement. Data will be made available on request.

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