Examining Vulnerability to Foodborne Illness:

A Comprehensive Review of "Clinically Vulnerable Groups"

Research undertaken on behalf of
Food Standards Scotland by:

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Abbreviations and acronyms

ACMSF – Advisory Committee on the Microbiological Safety of Food
AIDS – acquired immunodeficiency syndrome
APC – antigen-presenting cells
ARHAI – Antimicrobial Resistance & Healthcare Associated Infection Scotland
AUD – Alcohol Use Disorder
B-cell - bursa-derived cells
CD (e.g. CD4, CD8) – cluster of differentiation
CDC – Centers for Disease Control and Prevention
CFSAN – Center for Food Safety and Applied Nutrition
CI – confidence interval
CNS – central nervous system
CTLA-4 – Cytotoxic T-lymphocyte associated protein 4
DEFRA – Department for Environment, Food and Rural Affairs
FAO – The Food and Agriculture Organization of the United Nations
FDA – United States Food and Drug Administration
FSA – Food Standards Agency
FSAI – Food Safety Authority of Ireland
FSIS – Food Safety and Inspection Service
GI – gastrointestinal
H2 blocker – histamine type-2 receptor antagonists/blockers
HIV – human immunodeficiency viruses
IBD – inflammatory bowel disease
IBS – irritable bowel syndrome
IFN-γ – Interferon gamma
IL (e.g. IL-B1, IL-1) – interleukins
LPS – lipopolysaccharides
NHS – UK National Health Service
OR – odds ratio
PFSE – Partnership for Food Safety Education
PPAR-γ – Peroxisome proliferator-activated receptor gamma
PPI – proton pump inhibitors
PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRISMA-ScR – PRISMA extension for scoping reviews
SEFARI – Scottish Environment, Food and Agriculture Research Institutions
STEC – Shiga toxin-producing *Escherichia coli*
TLR (e.g. TLR4-LPS) – toll-like receptors
TNF-α – tumour necrosis factor-alpha
UC – ulcerative colitis
UK – United Kingdom of Great Britain and Northern Ireland
UKHSA – UK Health Security Agency
US – United States of America
USDA – United States Department of Agriculture
WHO – World Health Organization
YOPI – Young, Old, Pregnant, and Immunosuppressed

Executive summary

Dissemination of food safety advice to consumers in Scotland is a key priority for Food Standards Scotland to reduce the risk of foodborne illness. Although food safety advice is relevant for all consumers, the level of risk from foodborne illness is not equal across consumer groups.

Some groups within society are more susceptible to foodborne illness. These groups are known as the "clinically vulnerable groups" to foodborne illness. This research focused on individuals whose physiological conditions predisposes them to foodborne infections, these are traditionally recognised as the YOPI (Young, Old, Pregnant, and Immunosuppressed) categories. Food Standards Scotland commissioned this research to undertake a comprehensive review of the current definition of "clinically vulnerable groups" and make recommendations for the updated definition of clinically vulnerable groups in relation to foodborne illness.

The research aimed to:

- Undertake a narrative review to obtain an in-depth understanding of the physiological background to susceptibility among clinically vulnerable groups.
- Consolidate Scottish prevalence data to determine who are the clinically vulnerable groups in Scotland, with regards to Campylobacter, Salmonella, Shiga toxin-producing *Escherichia coli* (STEC), *Listeria monocytogenes* and norovirus.
- Collate additional evidence from comparable developed countries to undertake a systematic review of foodborne illness prevalence among clinically vulnerable groups.
- Identify the current definitions of clinically vulnerable groups used by other food safety organisations to establish the groups most referred to as being clinically vulnerable.
- Present research findings in an expert panel consultation to help inform recommendations regarding the clinically vulnerable group definition.
- Explore suitable food safety messaging for clinically vulnerable groups with people in Scotland.

By integrating physiological explanations with prevalence data, the study has successfully provided a comprehensive understanding of foodborne illness susceptibility among clinically vulnerable groups. Among older adults and children, susceptibility is heightened due to immune system factors, while chronic conditions and associated medications further increase vulnerability. Prevalence of foodborne illnesses varies among different groups and regions, with Scotland showing higher rates of foodborne illness among older adults compared to similar countries.

The study identified clinically vulnerable groups beyond the traditionally recognised YOPI (Young, Old, Pregnant, and Immunosuppressed) categories, such as proton pump inhibitor users, people with cancer, diabetes, rheumatoid arthritis, and inflammatory bowel disease. However, existing definitions of clinically vulnerable groups used by food safety organisations often overlook these groups, emphasizing the need for broader recognition and surveillance efforts.

The expert panel consultation discussions considered categorisation of older adults, the need for enhanced surveillance for clinically vulnerable groups, the importance of targeted communication and the role of health care professionals and food safety organisations in dissemination, and the need to explore socio-demographic and behavioural factors.

Prevalence data associated with specific behaviours, socio-economic and lifestyle factors were beyond the scope of this report and are considered as part of the SEFARI Fellowship project with Food Standards Scotland which specifically explores the lifestyle factors of older adults associated with foodborne illness (SEFARI, 2023).

During the discussions with people over the age of 65 years, pregnant individuals and people undergoing cancer treatment were identified as being clinically vulnerable to foodborne illness. Participants were generally unaware that they may be at an increased risk of foodborne illness due to age or underlying conditions, nevertheless, many were able to comprehend immune system modifications when given a rationale. Discussions indicated the need to enable people to self-identify if they are at increased risk of foodborne illness. Some found it easier to accept vulnerability resulting from a medical conditions or medications, rather than age alone, as denial about ageing was also discussed. Recommendations and preferences for future food safety education communication were made.

The recommendations for future research arising from this report relate to:

- Exploring consumer perceptions and preferences for effective food safety messaging.
- Undertaking consumer food safety research with overlooked groups such as proton pump inhibitor users and people with diabetes, rheumatoid arthritis, and inflammatory bowel disease.
- Obtaining an in-depth understanding of the lifestyle factors among older adults that may contribute to food safety perceptions and practices.
- Investigate the role and associated perceptions of healthcare professionals and care providers with regards to food safety communication.

Lay summary

Food Standards Scotland provides food safety advice to the public to reduce the risk of food poisoning in Scotland. However, there are some groups of people that are more likely of becoming ill with food poisoning, and these groups need targeted advice and information. Therefore, to better understand which groups are most affected by food poisoning, Food Standards Scotland commissioned this study.

The study confirmed that groups normally associated with food poisoning such as children, pregnant individuals, older adults, and people with suppressed immune systems were affected by food poisoning, however the rates of food poisoning among older adults were higher in Scotland than in other countries. It also highlighted that there are groups who are often overlooked such as people who use proton pump inhibitors, people with cancer, diabetes, rheumatoid arthritis, and inflammatory bowel disease.

Specific recommendations include improving surveillance, targeted communication, and understanding consumer perceptions. Future research needs to explore lifestyle factors among older adults, the food safety perceptions and practices of the overlooked groups, and the role of healthcare professionals in food safety communication.

1. Introduction

Dissemination of food safety advice to consumers to reduce foodborne illness in Scotland is a key priority for Food Standards Scotland. Although food safety advice is relevant for all consumers, the level of risk from foodborne illness is not equal across consumers, with some groups within society being more susceptible to or at greater risk of severe illness from acquiring foodborne illness.

These groups are known as the "clinically vulnerable groups" to foodborne illness, they traditionally are classed as those with an immature or weakened immune system, whether a result of illness (immunocompromised), age (under 4 or over 65 years old) or pregnancy. However, these are vague definitions which may not accurately reflect the level of risk within a group.

To ensure that the definition of clinically vulnerable populations used in their agency is based on current evidence and facilitates appropriate future food safety messaging, Food Standards Scotland initiated a review of the current definitions of "clinically vulnerable groups", based on the prevalence of the five pathogens most frequently associated with foodborne transmission: Campylobacter, Salmonella, Shiga toxin-producing *Escherichia coli* (STEC), *Listeria monocytogenes* and norovirus.

2. Aims and objectives

The overarching aim of this research is to undertake a comprehensive review of the current definition of "clinically vulnerable groups" and to make recommendations for the updated definition of clinically vulnerable groups in relation to foodborne illness. The specific objectives include:

- Determine who are the clinically vulnerable groups in Scotland, with regards to foodborne illness.
- Collate additional evidence from peer-reviewed publication from comparable countries to determine the groups getting ill from foodborne illness.
- Identify the current definitions of clinically vulnerable consumers used by other food safety organisations worldwide.
- Conduct expert panel consultations to consider definitions of clinically vulnerable groups.
- Undertake discussions with consumers to consider recommendations for food safety messaging to clinically vulnerable groups.
- Consolidate recommendations regarding the clinically vulnerable group definition.

3. Methodology

To enable a comprehensive review of the current definition of "clinically vulnerable groups", the research consisted of six distinct phases:

i) Literature review of physiological background to susceptibility.
ii) Consolidation of Scottish prevalence data.
iii) Systematic review of foodborne illness prevalence among clinically vulnerable groups.
iv) Review of clinically vulnerable group definitions.
v) Expert panel consultation to consider clinically vulnerable groups.
vi) Discussion groups with consumers to consider food safety messaging to clinically vulnerable groups.

Prior to undertaking the research, ethical approval was obtained from the Healthcare and Food Ethics Committee at Cardiff Metropolitan University (Reference: Sta-8006).

3.1. Literature review of physiological background to susceptibility

A narrative review was conducted to identify the physiological conditions underlying the clinical vulnerabilities and determine the causes of increased susceptibility to foodborne infections among clinically vulnerable groups. This approach was chosen because of the necessity to integrate several concepts relevant to foodborne infections including the changes in immunity over lifespan, stages of life, chronic disease, and temporary or prolonged pharmacological therapies.

The review was conducted in the following steps:

i) identification of physiological conditions leading to vulnerability,
ii) search and identification of studies describing the physiological aspects related to infections and immunological responses, and
iii) summary of the synthesized information.

3.2. Consolidation of Scottish prevalence data

To enable identification of the groups who are getting ill with the five foodborne pathogens of interest in Scotland, published data from Public Health Scotland and Food Standards Scotland were accessed. Unpublished reports and datasets were obtained from Public Health Scotland. In Scotland, notifiable foodborne pathogens include *L. monocytogenes,* Salmonella, Campylobacter and STEC. Cumulatively, data from Scotland included:

- *L. monocytogenes*: 166 confirmed cases between 2012 – 2022.

- Salmonella: 3,726 confirmed cases between 2013 – 2017.
- Campylobacter: 30,196 confirmed cases between 2013 – 2017.
- STEC: 3,358 confirmed cases between 2012 – 2023.
- Norovirus: 15,725 confirmed cases between 2012 – 2023.

Where specific gaps in data existed, personal communications with Public Health Scotland were utilised. Data were reviewed and analysed to provide a breakdown according to the five pathogens and specific clinically vulnerable groups.

3.3. Systematic review of foodborne illness prevalence among clinically vulnerable groups

A systematic review approach was used to identify and analyse the existing empirical evidence on the prevalence of foodborne illness among clinically vulnerable groups. Pre-determined inclusion criteria were used to explore the extent, range, and nature of the available evidence on the topic (Tricco *et al.*, 2018). The review was conducted in a transparent, multi-step process and the reporting guidelines for systematic scoping reviews, PRISMA-ScR, were followed (Arksey & O'Malley, 2005; Tricco *et al.*, 2018).

The following steps were included:

i) the review of the study justification,
ii) definition of the research question,
iii) identification of relevant studies,
iv) study selection,
v) extraction and charting of the data, and collation, summary, and reporting of the results (Arksey & O'Malley, 2005; Tricco *et al.*, 2018).

The following terms were defined to conceptualize the review.

i) **Population:** The review targeted clinically vulnerable population groups. Any conditions or life stages that may impact the immune system were considered including pregnancy, neonates, children, ageing population, cancer, diabetes, rheumatoid arthritis, multiple sclerosis, inflammatory bowel disease, other autoimmune disorders, eating disorders, HIV/AIDS, transplant recipients, persons receiving treatments, medications, and other conditions that suppress immunity. These groups were determined based on researcher discussions and a review of key publications (e.g., ACMSF, 2009; Lund, 2015; Lund & O'Brien, 2011).
ii) **Setting/Geographic scope:** The review included relevant literature on the prevalence of foodborne human pathogens in the UK, EU, USA, Canada, Australia, and New Zealand.
iii) **Outcomes:** The review considered cross-sectional or longitudinal prevalence surveys, surveillance reports, or risk factor studies but excluded outbreak investigations, nosocomial outbreaks, and case reports.

The PRISMA flow diagram showing the steps in the review process and the number of identified studies is presented in Figure 1.

3.3.1. Search Strategy

To identify the published articles reporting the prevalence of foodborne illness among clinically vulnerable groups, a comprehensive search strategy was developed in consultation with a research librarian. The search strategy was comprised of three major thematic blocks using keywords and subject headings to identify articles covering vulnerable populations, foodborne pathogens, and relevant outcomes. The search terms were determined based on researcher discussion and a review of key publications (e.g., ACMSF, 2009; Lund, 2015; Lund & O'Brien, 2011) that describe food safety risks in clinically vulnerable groups and the consensus of the research team. The search was limited to studies from countries within the geographic scope of the review. The search terms were tested iteratively, and a final search string was developed using database-specific syntax. For consistency, the same search terms were used in all searched databases. Table 1 presents a summary of the final set of search terms.

Table 1. Search terms with thematic blocks combined using the "AND" operator.

Filter	Search terms
Population	"vulnerable populations" OR "vulnerable people" OR "clinically vulnerable groups" OR "vulnerable groups" OR underserved OR disadvantaged OR marginalized OR minorit* OR underprivileged OR at-risk OR poverty OR poor OR "social status" OR "social class" OR "low-income population" OR inequality* OR "socioeconomic status" OR "socioeconomic factor*" OR deprivation elderly OR geriatric* OR senior OR gerontolog* OR (((age OR aged) NEAR/3 (over OR older) NEAR/2 (60 or 65 or 70 or 75 or 80 or 85 or 90 or 95))) OR (older NEAR/1 (adult$ OR m?n OR wom?n OR person$ OR people)) OR "middle age" OR (((Age OR aged) NEAR/3 (under OR younger) NEAR/2 (5 OR 4 OR 3 OR 2 OR 1))) OR kindergarten OR "child day care" OR "child care" OR preschool OR "nursery school" OR infancy OR newborn*OR new-born OR infan* OR neonate* OR baby OR babies OR toddler* OR preschool* OR child* OR young* OR youth* diabet* OR "liver disease*" OR cirrhosis OR "kidney disease*" OR alcohol* OR hiv OR "human immunodeficiency virus" OR aids OR "autoimmune diseases" OR cancer* OR transplant* OR stress OR "gastrointestinal disease*" OR "crohn disease" OR "crohn's disease" OR hyperlipoproteinemia OR "bowel disease" OR "bowel syndrome" OR "bowel disorder" OR malnutrition OR "nutritional deficienc*" OR undernutrition OR malnourish* OR "food insecurity" OR pregnancy

Filter	Search terms
	OR smoking OR vaping OR "protein-pump inhibitor*" OR ppi OR "gastro-oesophageal reflux" OR immunosuppress* OR immunocompromised OR hypogammaglobulinemia OR immunodeficient* OR immunosuppressant* OR neoplasm OR ulcer* OR coeliac OR gastritis OR arthritis OR "immunologic factors"
Foodborne human pathogen	(food OR foodborn* OR food-born* OR "foodborn* disease*" OR "food contamination*" OR "food poisoning*") AND (campylobacter* OR "campylobacter infection*" OR salmonell* OR "salmonella infections*" OR escherichia OR "e. coli" OR stec OR o157 OR non-o157 OR "escherichia coli infections" OR listeria OR listerios* OR norovirus OR caliciviridae OR "norwalk virus" OR "norovirus infections" OR toxoplasm*)
Outcome	incidence* OR prevalence OR outbreak* OR endemic* OR rate* OR occurrence* OR epidemic* OR epidemiolog*OR frequenc* OR case* OR infection* OR hospitali*
Country	australia OR austria OR "baltic states" OR belgium OR canada OR "czech republic" OR denmark OR estonia OR finland OR france OR germany OR greece OR hungary OR iceland OR ireland OR italy OR latvia OR luxembourg OR netherlands OR "new zealand" OR norway OR poland OR portugal OR scandinavia OR "slovak republic" OR slovenia OR spain OR sweden OR switzerland OR "united states" OR "western europe" OR "european union" OR "united kingdom" OR britain OR england OR scotland OR wales

The searches were conducted in three bibliographic databases considered most relevant to the review: Web of Science Core Collection, CAB Abstracts and Global Health (via Web of Science), and MEDLINE (via Web of Science) using institutional subscriptions at The Ohio State University. The search was limited to journal articles. The search strategy for each database, is in Appendix 1.

The final searches in all bibliographic databases were performed on October 10, 2023, and upon completion, 4,756 records with a publication date of 2000 or later were retrieved (publications prior to this date were excluded due to relevance and changes in surveillance methods). All records found in the search were imported into the reference management software EndNote™ (® Clarivate, Version 21.2) and de-duplicated to remove redundant citations identified from multiple databases. After de-duplication, 2,794 unique records were uploaded to the web-based software platform Covidence (Veritas Health Innovation, Melbourne, Australia https://www.covidence.org/) which was used to facilitate article screening and data extraction.

Articles were screened based on titles and abstracts using the inclusion criteria described below. While any uncertainties during the screening process were discussed and reconciled, due to the time constraints, only one reviewer performed

the screening of each article. Full texts of all articles identified as potentially relevant were retrieved (*n*=315, *n*=2479 excluded), and each full-text article was reviewed by one reviewer. Based on the full-text screening, another 180 studies were excluded, and the reasons for exclusion documented. A total of 135 studies were confirmed to be relevant and included in the final review. Based on suggestions from the expert panel consultations, three additional studies from sources other than the bibliographic databases searched were added, for a total of 138 studies included in the final map (Figure 1).

3.3.2. Inclusion/exclusion criteria

For studies to be included in the review of empirical evidence on the prevalence of foodborne illness among clinically vulnerable groups, they must meet all the following inclusion criteria:

- Focus on clinically vulnerable population groups (e.g., pregnant persons, neonates, children, ageing population, cancer, diabetes, rheumatoid arthritis, multiple sclerosis, inflammatory bowel disease, other autoimmune disorders, eating disorders, HIV/AIDS, transplant recipients, persons receiving treatments, medications, and other conditions that suppress immunity).
- Focus on foodborne human pathogens Salmonella, Campylobacter, *E. coli* (STEC and other), *L. monocytogenes*, or norovirus.
- Focus on the UK, EU, USA, Canada, Australia, or New Zealand (these countries list Salmonella, Campylobacter, STEC and *L. monocytogenes* as notifiable pathogens).
- Original research describing the prevalence of foodborne human pathogens, including any raw prevalence (numerator/denominator), incidence data per population, or effect estimates (OR, RR) in any of the clinically vulnerable groups.
- Study designs were peer-reviewed cross-sectional or longitudinal prevalence surveys, surveillance reports, or risk factor studies testing the vulnerabilities as risk factors for foodborne illness prevalence.
- Date of publication is 2000-present.
- Language of publication is English.

Consequently, studies that were excluded met at least one of the following exclusion criteria:

- The study did not report on any vulnerable population group as defined above.
- The study did not focus on relevant foodborne human pathogen listed above.
- The study focus was geographically outside of the scope of the review.
- The study focus was on outbreak investigations, nosocomial outbreaks, and case reports.
- The study did not contain original data from 2000-present.
- The study has the main body of text written in a language other than English.

3.3.3. Data extraction

To facilitate the data extraction process for the 138 studies that met the eligibility criteria, a data extraction template was created in Covidence. Due to time limitations, only one reviewer performed the data extraction, as with the screening process. In addition to the bibliographic information, the following data variables were extracted for each study: (i) foodborne human pathogen, (ii) incidence date, (iii) study type, (iv) country of study, (v) clinically vulnerable group (physiological), and (vi) clinically vulnerable group (demographic).

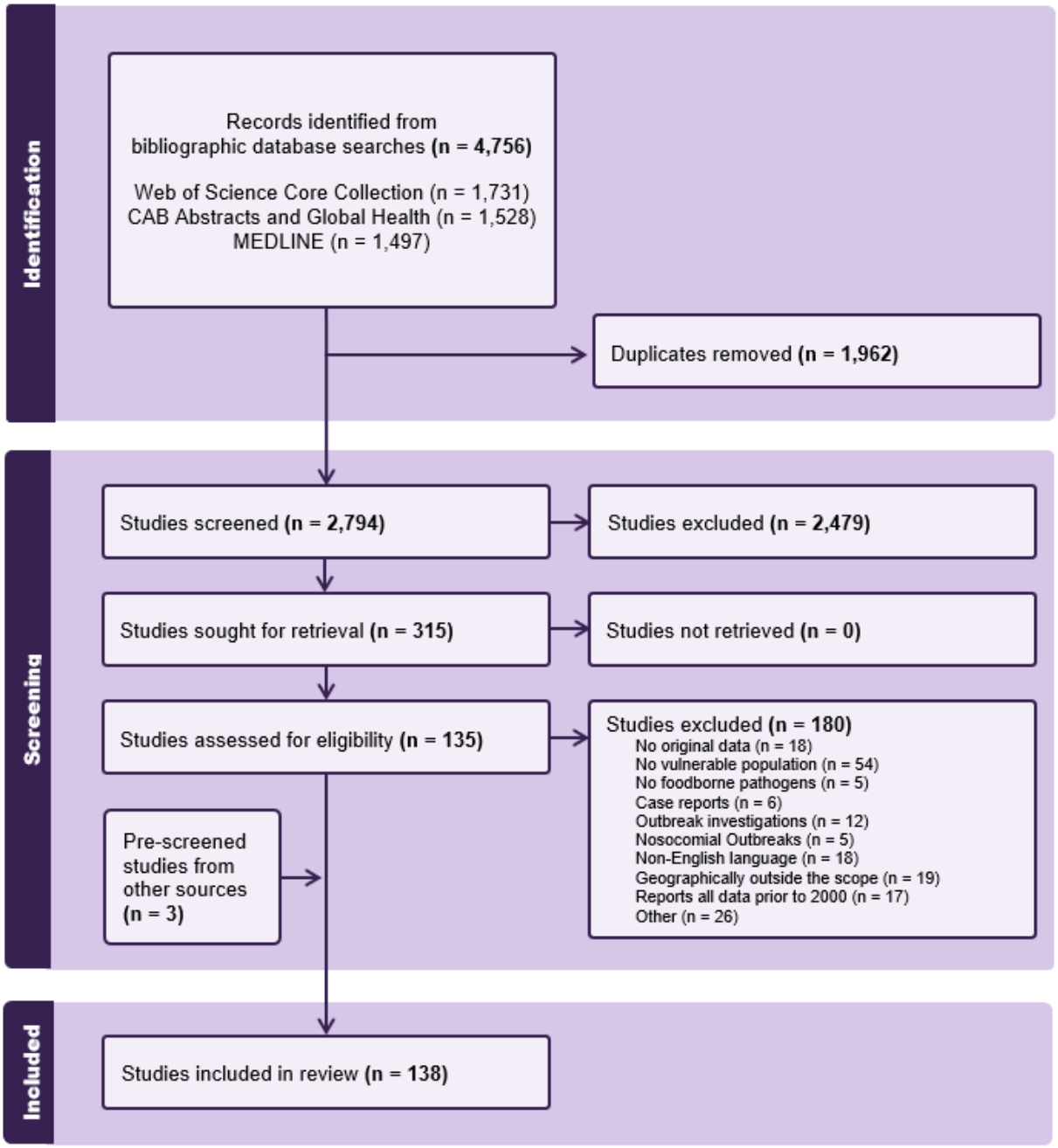


Figure 1. PRISMA flow diagram for review of prevalence data.

3.4. Review of clinically vulnerable group definitions

In addition to collating evidence to determine who is getting ill from foodborne illness, the research aimed to identify the current definitions of clinically vulnerable consumers used by other food safety organisations worldwide.

3.4.1. Grey literature search strategy

As part of the review process for clinically vulnerable groups definitions, a grey literature search was conducted to gather information from publications and websites produced by various global and national food safety organisations, as much of this information is expected to exist outside of peer-reviewed publications. For this purpose, the research team compiled a list of 31 food safety organisations located in the UK, EU, USA, Canada, Australia, and New Zealand to be included in this review.

Because most of the grey literature sources did not support advanced search features, a simplified search strategy was developed based on the search terms and concepts used for the bibliographic database searches. To ensure consistency, the searches were conducted in Google, limiting the results to the website of the organisation being searched. Each organisation's website was searched using the same set of search strings: site: [organisational domain] AND [human pathogen] AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR "food safety"). For the complete search strategy for each organisation, please see Appendix 2.

The searches were conducted between November 16, 2023, and February 23, 2024. The estimated number of hits for each search string was recorded. The first 60 hits were screened for relevance by one of three reviewers. Each reviewer was trained, and reviewer consistency was checked. Relevance was determined by assessing whether the retrieved document referred to any clinically vulnerable group in the context of foodborne illness. Peer-reviewed publications and journal articles were excluded from this review. Ten consecutive non-relevant or duplicated search hits were used as termination cut-off. All relevant documents were saved as PDF files, and data were extracted.

3.4.2. Data extraction

Data extraction was performed using Qualtrics software Version XM (Qualtrics, Provo, UT, USA; https://www.qualtrics.com). Document titles, publication years, and authors were recorded. Extracted data included document types, intended audiences, clinically vulnerable groups, and foodborne pathogens. Specific age cut-offs for children and older adults were documented. Documents were assessed for inclusion of the explanations of vulnerabilities, and for citing the references to support the vulnerability statements. Complete definitions were recorded, and PDF copies of the documents were saved. The data extraction tool can be seen in Appendix 3.

3.5. Expert panel consultation to consider clinically vulnerable groups

Expert panels are a useful method for offering valuable insight into scientific evidence and to explore what experts believe about its application to a given situation (Coulter *et al.*, 2016).

Given the complexity of the work undertaken, and to enable meaningful recommendations for Food Standards Scotland regarding future definitions of clinically vulnerable groups, expert panel consultations were undertaken.

3.5.1. Identification and recruitment of experts

The researchers identified experts in relevant fields including representatives from global food safety organisations and experts in areas including food safety education, microbiology, medicine, nutrition, immunology, physiology, psychology, pharmacology, and epidemiology.

Of the identified experts (*n*=30) contacted by the researchers, 26 agreed to be involved in the expert consultation. Three expert panels were conducted during February 2024 with the consolidated panel of experts (*n*=21) based on availability and time-zone restrictions. The experts who were not able to participate in the panel discussions reviewed the report and recommendations arising from the expert panels and provided further feedback (*n*=5). A list of the experts who wished to be named in the report can be found in Appendix 4.

3.5.2. Conducting expert panel consultations

In total three expert panel consultation session were undertaken, each taking 2 hours to complete. The sessions consisted of two distinct parts, during the first part, the researchers presented key findings relating to:

- The physiological background to susceptibility for various clinically vulnerable groups.
- The prevalence of foodborne illnesses among clinically vulnerable groups in Scotland and comparable countries.
- Findings from the review of clinically vulnerable group definitions.

During the second part, structured discussion was facilitated and moderated by the researchers using predetermined prompts to guide discussion which consisted of four distinct sections:

- Appropriateness of clinically vulnerable groupings.
- Definitions of vulnerability.
- Recommendations for communicating with clinically vulnerable groups
- Open discussion regarding any other relevant points.

All panel discussions were undertaken and recorded using Microsoft Teams, which was utilised to generate transcripts of the discussion sessions, and a research assistant attended all panel discussions to take detailed notes.

3.5.3. Expert panel data consolidation and analysis

Following completion of the expert panel consultations, the transcripts were downloaded and reviewed independently by the researchers. The research team convened to consolidate the transcripts and detailed session notes and categories the points of discussion from each meeting into key themes relating to the predetermined prompts and any additional discussion points brought up by the expert panels to formulate recommendations for Food Standards Scotland.

3.6. Discussion groups with consumers to consider food safety messaging for clinically vulnerable groups.

To support the development of future food safety messaging interventions it is of importance to consider the preexisting perceptions and the communication preferences of the specific target audience (Evans & Redmond, 2022). Involvement of the target audience in intervention development is believed to increase potential effectiveness of interventions (Green *et al.*, 1996). A review of previous consumer food safety education interventions established that clinically vulnerable groups are under-represented as targets of interventions (Sivaramalingam *et al.*, 2015); furthermore, less than half of consumer food safety education interventions have engaged with the target audience in the development, delivery, and evaluation of interventions (Sivaramalingam *et al.*, 2015). Inclusion of the intended audience in the development of targeted interventions is essential (O'Cathain *et al.*, 2019); tailored interventions based upon a target audience's circumstances can be developed through co-creation with stakeholders (Leask *et al.*, 2017). The co-creation of intervention development needs to consider the current practices, preferences and experiences of the intended audience (Ohern & Rindfleisch, 2010).

To give Food Standards Scotland meaningful insight to appropriate food safety messaging for clinically vulnerable groups, there is a need to engage with this group. It was agreed upon with Food Standards Scotland that a complementary research fellowship would be utilised to capture meaningful data for this report.

3.6.1. Complementary Food Standards Scotland research

Currently, Food Standards Scotland have a Fellowship project with the Scottish Environment, Food and Agriculture Research Institutions (SEFARI) to explore the lifestyle factors which cause members of the older population to become ill with

foodborne disease, the recipient of the Fellowship is the principal investigator for this report on clinically vulnerable groups.

The first phase of the SEFARI fellowship project conducted in-depth telephone interviews and online focus groups with individuals over the age of 65 and those who support relatives over 65 years (*n*=80). These sessions explored factors influencing food shopping, storage, cooking, and eating behaviours, as well as food safety perceptions and practices (Evans, 2024). To benefit this report on clinically vulnerable groups, additional questions were incorporated into the second phase of data collection for the SEFARI fellowship.

Although the Fellowship focuses on one clinically vulnerable group, namely people over the age of 65, the group often includes other clinically vulnerable groups due to prevalence of disease or medication. Therefore, it was deemed appropriate to utilise this group to complement the findings of this report.

3.6.2. Recruitment of Participants

Recruitment was carried out through an online advert on the Food Standards Scotland Facebook page and posters displayed on community notice boards in shops, community centre, leisure centres and libraries in the areas surrounding the selected venues for data collection. Interested participants signed up by completing an online form or by contacting the research team via telephone or email.

3.6.3. Development of discussion group Interview Schedule

Three statements defining clinically vulnerable groups were developed. A standardised semi-structured interview schedule was created to explore preferences for wording and information. The interview schedule aimed to gather insights into the participants' communication preferences and perceptions regarding food safety messaging. To facilitate discussion and explore preferences for risk communication, three different risk statements regarding clinically vulnerable groups to listeriosis were developed:

- **Simple YOPI classification:** A short, straightforward statement based on the standard YOPI (Young, Old, Pregnant, Immunocompromised) categories.
- **Extended YOPI classification:** This statement included specific chronic illnesses and treatments/medications identified in this report that result in reduced immune function.
- **Detailed vulnerability explanation:** An extended statement that specifically defined why the listed groups are clinically vulnerable to foodborne illness, providing the most comprehensive information.

These statements were color-coded and presented to participants in ascending order of complexity during the discussion groups.

3.6.4. Conducting discussion groups

Six discussion groups were conducted in various locations across Scotland, (Stranraer, Glasgow (two), Aberdeen (two) and Inverness) during May 2024 with a total of 50 participants. Each session was audio recorded.

3.6.5. Data collection and analysis

All discussion group sessions were audio recorded and subsequently transcribed. After transcription and checking the transcripts against the original audio recordings, the researcher reviewed the transcripts and coded participant statements according to the predefined codebook using NVivo, adding sub-nodes where necessary.

The research team reviewed the coded themes to summarise the responses regarding the preferences for food safety messaging for clinically vulnerable groups. Recommendations for future communication strategies were based on these findings.

Full details regarding the methodology utilised in this phase of work, can be found in the SEFARI report (SEFARI, 2023).

4. Results

The results in this report consist of four sections:

- **Section 4.1:** Underlying vulnerable conditions and prevalence of foodborne illness. The consolidated findings of the methods described in sections 3.1. 3.2, and 3.3.
- **Section 4.2:** Review of clinically vulnerable group definitions. Findings of the methods described in section 3.4.
- **Section 4.3:** Expert panel consultations. Findings of the methods described in section 3.5.
- **Section 4.4:** Discussion groups with consumers to consider food safety messaging to clinically vulnerable groups. Findings of the methods described in section 3.6.

4.1. Underlying vulnerable conditions and prevalence of foodborne illness

Vulnerability of populations change over the human lifespan and differs at different stages of life. Vulnerable populations often include infants, ageing adults, pregnant individuals, individuals with chronic illnesses, those that receive medications for various genetic and chronic conditions, and all individuals with compromised immune systems, such as those with diabetes or HIV/AIDS (FAO; & WHO;, 2022; Gillespie *et al.*, 2006). Socioeconomic factors, including poverty, homelessness, and limited access to healthcare, can also contribute to vulnerability (Newman *et al.*, 2015; Quinlan, 2013). In addition, the risk of foodborne infections may be elevated due to the unknown individual genetic factors affecting their immune systems and the composition of their intestinal microbiomes (Klebanov, 2018).

The results presented in this section consolidate the information collected as described in sections 3.1, 3.2, and 3.3, to provide the context and physiological background that makes the groups clinically vulnerable and synthesize the existing disease prevalence information for the pathogens of interest according to each of the clinically vulnerable groups without the insights into the behavioural and socioeconomic aspects of foodborne disease vulnerabilities.

4.1.1. Consolidation of Scottish data

The incidence of foodborne illness varies with age. Data detailing prevalence of the five pathogens of interest in Scotland among children and older adults were available (Table 2).

Table 2 summarises the data obtained from Public Health Scotland and Food Standards Scotland and provides context regarding the frequency of the underlying condition or clinically vulnerable group within the Scottish population (5,436,600 as reported in Scotland's Census (2023)).

Breakdown of data among clinically vulnerable groups other than older adults and children for all pathogens were not available. Data detailing *E. coli* and norovirus were particularly lacking in relation to the clinically vulnerable groups. Prevalence of listeriosis among clinically vulnerable groups was most frequently available.

Table 2. Prevalence of five key foodborne pathogens in Scotland according to clinically vulnerable groups. (Percentage of cases reported to be among clinically vulnerable groups)

Clinically vulnerable groups	Percentage of Scottish population (5,436,600 as reported in Scotland's Census (2023)).	*L. monocytogenes* [a]	Salmonella [b]	STEC [c]	Campylobacter [d]	Norovirus [e]
Adults aged ≥65 years	20% of population (Scotland's Census, 2023).	68%	15%	14%	23%	60%
Children aged <5 years	4.5% of population (National Records of Scotland, 2023b).	4%	14%	18%	5%	20%
Pregnancy associated	44,557 maternities per year (Public Health Scotland & National Statistics, 2023a).	4%	*	*	*	*
Cancer	35,379 new diagnoses per year (Public Health Scotland & National Statistics, 2023b).	19%	*	*	*	*
Rheumatoid Arthritis	0.8% of population (British Society for Rheumatology & Scottish Society for Rheumatology, 2018).	1.2%	*	*	*	*
Diabetes	6.2% of the population (NHS Scotland & Scottish Diabetes Data Group, 2023).	10%[f]	5%[g]	*	7%[g]	*
HIV/AIDS	0.1% of population (6600 people (Public Health Scotland, 2023).	*	*	*	*	*
Alcohol use disorder (AUD)	23% of population (hazardous or harmful levels (Scottish Government, 2022).	4%[f]	*	*	*	*
Proton pump inhibitors (PPI)	Data not available. (4.2 million annual prescriptions (Public Health Scotland, 2022)).	*	25%[h]	*	34%[h]	*
Transplant recipients	0.01% of population per year (NHS Blood and Transplant, 2023).	*	*	*	*	*
Inflammatory bowel disease (IBD) / irritable bowel syndrome (IBS) / Crohn's disease	0.9% of population (Crohn's & Colitis UK, no date).	3% [f]	*	*	*	*
Antibiotic use	Data not available.	*	10.5%[i]	*	6%[i]	*
Corticosteroids use	Data not available.	*	*	*	*	*

[a] *L. monocytogenes:* 166 cases (2012 – 2022) (Brownlie, 2024; Public Health Scotland, no date)**.**
[b] Salmonella: 3,726 cases (2013 – 2017) (Brownlie, 2024; Public Health Scotland, Unpublished-d)**.**
[c] Shiga toxin-producing *Escherichia coli:* 3,358 cases (2012 – 2023) (Public Health Scotland, Unpublished-a)**.**
[d] Campylobacter: 30,196 cases (2013-2017) (Brownlie, 2023; Food Standards Scotland, 2020a).
[e] Norovirus: 15,725 cases (2012 – 2023) (Public Health Scotland, Unpublished-c)**.**
* denotes data not available from Public Health Scotland/Food Standards Scotland.
[f] had the condition listed as an underlying condition.
[g] prescribed diabetes medication 365 days preceding infection.
[h] prescribed PPIs 90 days preceding infection.
[i] prescribed an antibiotic 30 days preceding infection.

4.1.2. Studies included in the systematic review

As described in section 3.3, to supplement and complement the data obtained from Scotland (Table 2), a total of 138 studies were reviewed. Most studies originated from the US (27%) and UK (14%), with other studies coming from Australia (7%), Canada (6%) and various European countries (Table 3).

Table 3. List of countries in included prevalence studies (*n*=138).

Country	n	%
United States	36	27%
United Kingdom	22	14%
Australia	9	7%
Canada	8	6%
Poland	8	6%
Italy	7	5%
Spain	7	5%
France	6	4%
Netherlands	6	4%
New Zealand	6	4%
Switzerland	4	3%
Denmark	3	2%
Germany	3	2%
Ireland	3	2%
Finland	2	1%
Portugal	2	1%
Romania	2	1%
Latvia	1	1%
Norway	1	1%
Lithuania	1	1%
Turkey	1	1%

As indicated in Table 4, *L. monocytogenes* was the most frequently included pathogen (58 studies) whilst norovirus was only included in 11 of the reviewed studies. Forty-eight studies included data detailing Salmonella, 37 included data detailing *E. coli,* whilst 25 included data on Campylobacter. It is worth noting that the four pathogens of interest are notifiable organisms in the countries listed, while norovirus is not notifiable other than in Scotland, Ireland, and Canada, a table indicating notifiable organisms by country can be seen in Appendix 6.

Older adults and children were the two clinically vulnerable groups that were most frequently included in 84 and 72 of the studies, respectively. Pregnancy-associated cases were included in 37 studies whilst cancer and rheumatoid arthritis were included in 29 studies each.

Table 4. Inclusion of data detailing key pathogens and clinically vulnerable groups in reviewed studies (*n*=138).

Clinically vulnerable groups	*L. monocytogenes*	Salmonella	*E. coli*	Campylobacter	Norovirus
Pregnancy (*n*=37)	37	0	0	0	0
Children (*n*=72)	12	34	21	22	3
Older adults (*n*=84)	49	21	11	9	2
Proton pump inhibitors (*n*=11)	5	3	0	4	0
Rheumatoid Arthritis (*n*=29)	6	2	0	0	0
Diabetes (*n*=20)	19	1	0	0	0
IBD/IBS/Crohn's (*n*=4)	3	0	0	1	0
Cancer/cancer treatment (*n*=29)	27	2	0	0	0
HIV/AIDS (*n*=10)	8	2	0	0	0
Alcohol use disorder (*n*=12)	11	10	0	0	0
Transplant recipients (*n*=9)	7	1	0	1	0
Total (*n*=138)	58	48	37	25	11

In sections 4.1.3 – 4.1.14, where data exist, prevalence data for the five foodborne pathogens of interest are presented in tabular format according to each clinically vulnerable group. Note that not all studies included in the review provided prevalence data (for example, some only reported incidence data), therefore the number of prevalence studies shown in the table may be fewer than the total number of studies cited as referring to the pathogen for that clinically vulnerable group.

In addition to capturing data detailing the prevalence of foodborne illness among the clinically vulnerable groups, incidence rates were extracted from reviewed studies for the five pathogens according to the clinically vulnerable groups as presented in Table 5. Incidence rates were more widely available for *L. monocytogenes*, than for other pathogens. Incidence rates are discussed in more detail in sections 4.1.3 – 4.1.14 in relation to each clinically vulnerable group.

Table 5. Incidence rates of foodborne pathogens among clinically vulnerable groups from reviewed studies (number of cases per 100,000 people).

Clinically vulnerable group	*L. monocytogenes*	Salmonella	*E. coli*	Campylobacter	Norovirus
General population	0.07 – Norway (Antal *et al.*, 2007) 0.27 – UK (UK Health Security Agency, 2023) 0.28 – US (Pohl *et al.*, 2019) 0.29 – US (Silk *et al.*, 2013) 0.4 – US (Barkley *et al.*, 2016) 0.4 – Australia (OzFoodNet Working, 2004) 1.09 – Spain (Herrador *et al.*, 2019)	6.7 – Italy (Mughini-Gras *et al.*, 2012)	0.3 – Australia (OzFoodNet Working, 2004)	112 – Australia (OzFoodNet Working, 2004)	*
Pregnant individuals / Neonates	**Births:** 4.3 – Italy (Filipello *et al.*, 2017) 4.7 – Australia (OzFoodNet Working, 2004) 12.3 – New Zealand (Jeffs *et al.*, 2020) **Pregnancies:** 3.0 – US (Silk *et al.*, 2013) 3.73 – US (Pohl *et al.*, 2019) 5.6 – France (Goulet *et al.*, 2012) 7.19 – Spain (Herrador *et al.*, 2019)	*	*	*	*
Children	**<1 year:** 1.9 – US (Vugia *et al.*, 2002). **<5 years** 0.28 – Italy (Colarusso *et al.*, 2022) 1.7 – US (Barkley *et al.*, 2016)	**<2 years:** 207 – Poland (Sadkowska-Todys & Czarkowski, 2015) **<5 years:** 45 – US (Boore *et al.*, 2015) **<14 years:** 98.2 – Italy (Mughini-Gras *et al.*, 2012)	**<1 year:** 9.0 – US (Gould *et al.*, 2009) **<1-year (non-O157 STEC):** 3.93 – US (Gould *et al.*, 2013) **<2 years:** 4.9 – France (Jones *et al.*, 2023) 3.3 – France (Bruyand *et al.*, 2019) **<5 years (STEC):** 1.6 – Scotland (Public Health Scotland, 2020) 1.89 – US (Gould *et al.*, 2013) **<5 years:** 3.90 – UK (Adams *et al.*, 2019) 5.6 – US (Gould *et al.*, 2009) 6.8 – US (Vugia *et al.*, 2002) 9.0 – Scotland (Public Health Scotland, 2020)	**<1 year** 33.5 – US (Vugia *et al.*, 2002) **<5 years:** 578 – New Zealand (Baker *et al.*, 2007) 1.86 – Italy (Colarusso *et al.*, 2022) 578.1 – New Zealand (Baker *et al.*, 2007) **Males <5 years:** 5.19 – New Zealand (Spencer *et al.*, 2012) 218.3 – Australia (OzFoodNet Working, 2012) **Females <5 years:** 160.2 – Australia (OzFoodNet Working, 2012) 418 – New Zealand (Spencer *et al.*, 2012)	**<5 years:** 152– US (Grytdal *et al.*, 2016)
Older adults	**≥65 years:** 0.05 – France (Goulet *et al.*, 2012) 0.21 – Italy (Colarusso *et al.*, 2022) 1.3 – US (Silk *et al.*, 2013) 2.48 – Spain (Herrador *et al.*, 2019) **60–69 years:** 2.4 – Australia (Parisi *et al.*, 2019). 3.7 – Denmark (Jensen *et al.*, 2010) **≥70 years:** 1.33 – US (Pohl *et al.*, 2019) **70-79 years:**	**≥65 years:** 17.33 – Italy (Mughini-Gras *et al.*, 2012) **≥85 years:** 13 – US (Boore *et al.*, 2015)	**≥60 years:** 0.98 – England and Wales (Adams *et al.*, 2016) 0.22 – US (Gould *et al.*, 2013)	**Males ≥65 years:** 2.85 – New Zealand (Spencer *et al.*, 2012) **Females ≥65 years:** 2.41 – New Zealand (Spencer *et al.*, 2012)	**≥69 years:** 75.8 – US (Grytdal *et al.*, 2016)

Clinically vulnerable group	*L. monocytogenes*	Salmonella	*E. coli*	Campylobacter	Norovirus
	5.2 – Australia (Parisi *et al.*, 2019). 7.3 – Denmark (Jensen *et al.*, 2010) **≥75 years:** 0.98 – France (Goulet *et al.*, 2012) 1.7 – US (Vugia *et al.*, 2002) **≥80 years:** 3.1 – US (Barkley *et al.*, 2016) 4.8 – Australia (Parisi *et al.*, 2019) **80-89 years**: 12.1 – Denmark (Jensen *et al.*, 2010) **≥90 years:** 22.0 – Denmark (Jensen *et al.*, 2010)				
Rheumatoid Arthritis	2.71 – France (Goulet *et al.*, 2012)	*	*	*	*
Diabetes	**Type 1 diabetes:** 1.63 – France (Goulet *et al.*, 2012) **Type 2 diabetes:** 0.2 – France (Goulet *et al.*, 2012)	*	*	*	*
IBD/IBS/Crohn's	**Crohn's:** 1.98 – France (Goulet *et al.*, 2012)	*	*	*	*
Cancer	3.75 – France (Goulet *et al.*, 2012)	*	*	*	*
HIV/AIDS	2.68 – France (Goulet *et al.*, 2012)	*	*	*	*
Transplant	7.91– France (Goulet *et al.*, 2012)	*	*	*	*
Alcohol use disorder	*	*	*	*	*
Proton pump inhibitors	*	*	*	*	*
* Denotes no incidence rate data available from reviewed studies.					

4.1.3. Pregnant individuals and neonates as clinically vulnerable groups to foodborne illness

Hormonal changes during pregnancy instigate immunological modulation aimed at the growth and delivery of a healthy baby (Fuhler, 2020). However, the immune system reconfiguration does not necessarily imply that the immune function has been muted or that pregnant individuals have increased susceptibility to foodborne illness. The immune system in pregnancy is modulated to protect the host from infections and simultaneously to facilitate and protect the pregnancy. It is appropriate to refer to pregnancy as a unique immune condition that is modulated, but not suppressed. Host immune responses are dependent on the stage of pregnancy and on the pathogen (Entrican, 2002).

At implantation, the maternal immune system is active and fully functional. Over the course of pregnancy, as the foetus is growing, the immune system adapts to accommodate each phase of foetal development. The interactions between the maternal immune system and the foetus are complex, reinforcing the recognition, communication, trafficking, and repair by the immune cells. Pregnancy is a unique immune condition that is modulated, but not suppressed (Mor & Cardenas, 2010).

The maternal immune system relies on cell-mediated responses to fend off infections (Orefice, 2021), this response is pathogen specific. Pathogens contain unique molecules referred to as pathogen-associated molecular patterns which include lipopolysaccharides (LPS) of Gram-negative bacteria, peptidoglycan of Gram-positive bacteria and flagellin (Orefice, 2021). Pathogens with an intracellular life cycle like *L. monocytogenes* are engulfed by epithelial cells and multiply in the host cell cytoplasm. From there, the pathogen breaches the cell wall and moves onto the adjacent cells, bypassing antibodies, neutrophils, or any potential antibiotics in the extracellular fluid (Turvey & Broide, 2010). *L. monocytogenes* crosses the placental

barrier, impacting the foetus. Neonatal listeriosis is almost always acquired *in utero* (Marquis *et al.*, 2015).

In 2020, nearly half (47%) of all under-5 mortalities occurred among newborns. Infectious diseases (WHO, 2022), with gastrointestinal infections being the leading cause, accounted for 25% of fatalities during this period of life (Semmes *et al.*, 2020). A child is born with an immature innate and adaptive immune system, which develops and acquires memory as the child grows.

The first 28 days of life, referred to as the neonatal period, account for one half of infection-caused deaths globally (WHO, 2022). The innate immune system provides an early first line of defence against human pathogens and is orchestrated by non-specific cells such as monocytes/macrophages, neutrophils, and dendritic cells. These cells develop and mature during foetal life, but at different times (Simon *et al.*, 2015). While macrophage levels are supplemented to some extent by breast milk, a newborn's immune system cannot produce the large number of neutrophils required quickly enough to fight off infection from human pathogens. By the time sufficient neutrophil levels are reached, the baby will likely require medical attention. Newborns typically grow out of this vulnerability by two months of age. Infants up to 12 months of age still have a limited ability to mount robust immune responses, as their immature immune systems are under development. The reduced capability of simultaneous production of multiple cytokines upon immune stimuli persists throughout infancy (Georgountzou & Papadopoulos, 2017).

Adaptive immunity, which involves specialised antigen presenting cells, T-cells, and B-cells, (Chaplin, 2010) is naive in newborns and cannot recognise pathogens for a quick cellular response. T-cell dependent B-cell activation is not efficient due to diminished T-cell priming, and it takes longer for T-cells to produce cytokines to direct the immune response. The levels of cytotoxic T-cells that are needed for killing infected cells are low, correlating to low antibody production and poor responses to foreign antigens (Children's Hospital of Philadelphia, 2019). B-cell responses that are activated by LPS or repeating proteins found on the surface of pathogenic bacteria are diminished in newborns which directly results in increased susceptibility to bacterial infections, such as meningococcus, pneumococcus or those caused by *Mycobacterium tuberculosis* and *Salmonella* spp. (Simon *et al.*, 2015).

Infections in neonates and infants are more likely to develop into a severe disease, often resulting in fatality. For instance, among all cases of listeriosis resulting in meningitis in the Netherlands from 1976-1995, neonates developed neurological sequelae significantly more often than older individuals (Aouaj *et al.*, 2002). Foodborne pathogens that are often linked to infections in neonates include *L. monocytogenes,* Salmonella*,* and *E. coli*. Newborns receive a degree of immunity from their mothers, primarily through the transfer of antibodies across the placenta during pregnancy and through breast milk. Therefore, formula fed infants are more prone to gastrointestinal infections leading to a higher incidence of diarrhoea (Frank *et al.*, 2019; Tampubolon & Ronny, 2021). Technological developments in baby formula design have been underway to mitigate the shortcomings of current products available on the market (Bakshi *et al.*, 2023).

Pregnant individuals and neonates in Scotland

There were 44,557 maternities (a pregnancy ending in a live or stillbirth) in Scotland in 2022/23, at a rate of 43.2 per 1,000 women aged 15-44 years (Public Health Scotland & National Statistics, 2023a). Rates of maternal obesity and diabetes are increasing in Scotland, with over a quarter (27.9%) and nearly a tenth (9.3%) of maternities now affected by obesity and diabetes, respectively (Public Health Scotland & National Statistics, 2023a), these trends raise important concerns regarding comorbidities for susceptibility to foodborne illnesses. For example, the proportions of preterm delivery is increased among pregnant individuals with diabetes (Mackin et al., 2018), and infection is a significant clinical problem in preterm infants, who have significantly elevated risk of developing and succumbing to infections due to underdeveloped innate and adaptive immune systems (Collins et al., 2018). Gestational diabetes presents a similar risk to foodborne illness as diabetes among non-pregnant individuals (see 4.1.8).

There were 3,782 live babies born prematurely in 2022/23 which is equivalent to 8.4% of all live born babies. The vast majority (86%) of these were born between 32 – 36 weeks gestation (Public Health Scotland & National Statistics, 2023a).

Prevalence of foodborne illness among pregnant individuals and neonates

As indicated in Table 6, data regarding pregnancy associated cases of foodborne illness other than *L. monocytogenes,* were lacking both in the data obtained from Scotland and in the systematic review of prevalence studies.

Table 6 Prevalence of foodborne pathogens among pregnant individuals and neonates in reviewed studies (*n*=37) (*L. monocytogenes* *n*=37; Salmonella *n*=0; Campylobacter *n*=0; *E. coli* *n*=0; Norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were reported to be pregnancy associated cases)
L. monocytogenes	3% of cases in Denmark (Jensen *et al.*, 2010) 3% of cases in Latvia (Berzins *et al.*, 2009) 4% of cases in Finland (Suominen *et al.*, 2023) 4 – 17% of cases in Australia (Ashbolt *et al.*, 2002; Dalton *et al.*, 2011; Leung *et al.*, 2018; OzFoodNet Working, 2004) 7 – 11% of cases in Italy (Filipello *et al.*, 2017; Gori *et al.*, 2020; Mammina *et al.*, 2013) 9 – 15% of cases in Germany (Koch & Stark, 2006; Wilking *et al.*, 2021) 10% of cases in Portugal (Caplan *et al.*, 2014) 12 – 17% of cases in France (Goulet *et al.*, 2012; Goulet *et al.*, 2008) 12 – 21% of cases in England and Wales (Awofisayo *et al.*, 2015; Mook *et al.*, 2010; Public Health England, 2018; UK Health Security Agency, 2024) 13% of cases in England (Gillespie *et al.*, 2010) 14 – 23% of cases in US (Barkley *et al.*, 2016; Jackson *et al.*, 2010; Pohl *et al.*, 2019; Silk *et al.*, 2013; Voetsch *et al.*, 2007) 15% of cases in Romania (Caplan *et al.*, 2014) 16% of cases in Norway (Antal *et al.*, 2007) 17% of cases in the Netherlands (Doorduyn, de Jager, *et al.*, 2006) 23% of cases in Spain (Vallejo *et al.*, 2022)
Salmonella	No data available
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among pregnant individuals and neonates

Of the 166 confirmed cases of listeriosis in Scotland between 2012 – 2022, 4% were pregnancy associated cases (Public Health Scotland, no date). Although Public Health Scotland recognise that pregnant individuals, unborn and newly delivered infants are vulnerable to foodborne illness, in line with reporting in the rest of the UK and Europe, pregnancy associated cases are counted as one case, even when both the mother and infant are positive (Health Protection Scotland, 2020).

A total of 37 studies included data detailing the occurrence of foodborne illness among pregnant individuals, all of these were in relation to *L. monocytogenes*. As indicated in Table 6, the reviewed studies suggested that between 3% of listeriosis cases in Denmark (Jensen *et al.*, 2010) and Latvia (Berzins *et al.*, 2009) and up to 23% of cases in Spain (Vallejo *et al.*, 2022) were pregnancy associated cases. In France, the proportion of maternal-neonatal cases has declined significantly from 51% in 1987 to 24% in 1997 (Goulet *et al.*, 2006).

Many studies indicate that there were no maternal fatalities from listeriosis (Filipello *et al.*, 2017; Herrador *et al.*, 2019; Jackson *et al.*, 2010; OzFoodNet Working, 2012; Vallejo *et al.*, 2022), however, the potential severity of listeriosis was highlighted with studies reporting that due to foetal death, miscarriage or stillbirth, only 44 – 79% of pregnancy associated listeriosis cases resulted in a live birth (Antal *et al.*, 2007; Ashbolt *et al.*, 2002; Awofisayo *et al.*, 2015; Dalton *et al.*, 2011; Gori *et al.*, 2020; Jackson *et al.*, 2010; Pohl *et al.*, 2019; UK Health Security Agency, 2023; Voetsch *et al.*, 2007). These often occurred in the second trimester of pregnancy (Doorduyn, de Jager, *et al.*, 2006). In Australia, the median foetal gestational age at diagnosis was 35 weeks (range 18-40w) with deaths occurring between 18 and 32 weeks (Dalton *et al.*, 2011), thus suggesting that mortality is highest among preterm neonates.

As indicated in Table 5, incidence rates for listeriosis were reported per 100,000 births in Italy, Australia and New Zealand, which were 4.3, 4.7, and 12.3 respectively (Filipello *et al.*, 2017; Jeffs *et al.*, 2020; OzFoodNet Working, 2004) In the US, France and Spain, incidence was recorded by 100,000 pregnancies, which were 3.7, 5.6, and 7.2 respectively (Goulet *et al.*, 2012; Herrador *et al.*, 2019; Pohl *et al.*, 2019).

Salmonella, *E. coli,* Campylobacter and Norovirus among pregnant individuals and neonates

No data were available from Scotland or from reviewed studies regarding the occurrence of Salmonella, *E. coli,* Campylobacter, and norovirus among pregnant individuals. Although no data were captured regarding prevalence of other foodborne pathogens among pregnant individuals, the absence of data does not equate to absence of occurrence.

4.1.4. Children as a clinically vulnerable group

The immune system in children aged one and older is not fully developed. In this immune development period, the immune system's functional capacity is limited, with limited ability to generate a protective cellular and humoral response, leading to increased susceptibility to infectious diseases. As children age, they are exposed to infectious agents, antigen-specific cells expand massively in frequency and mature from highly proliferative naive cells into less proliferative effector and memory cells (Weyand & Goronzy, 2016).

The maturation of the immune system occurs in parallel with other processes, including exposure to food antigens, acquisition of the microbiome and introduction of different environmental pathogens (Hill *et al.*, 2020). The cumulative influence of environmental exposure and an individual's genetics, shape the human immune system. By about age five, the incidence of infectious diseases decreases in the population (Brodin *et al.*, 2015). While the age of adolescence is generally considered to be the age of immune system maturation, it is important to emphasise the variations in immune systems in individuals across the lifespan.

A study investigating 54 distinct immunological parameters among 675 individuals aged 2-85 over time, concluded that there was a high degree of variation in the immunological profiles of healthy individuals (Carr *et al.*, 2016). Genetic factors accounted for ~25-50% of measured immunological variation (De Jager *et al.*, 2015), and the local environment was shown to be a key factor in shaping the human immune system. The impact of environmental exposure to human pathogens is increased in children due to their developing behaviour (Ziehm *et al.*, 2015). For instance, oral sensory seeking behaviour contributes to the risks of infection.

Children in Scotland

The population of Scotland was estimated to be 5,436,600 on Census Day 2022, 16.1% of the population were children aged ≤15 years, and 247,100 of the population were aged ≤5 years, representing 4.5% of the population (National Records of Scotland, 2023b).

Prevalence of foodborne illness among children

Data on the prevalence of all five foodborne pathogens among children aged ≤5 years in Scotland were available (Table 2). In addition to this, more than half of the reviewed studies (72 out of 138) included data regarding children. The age categories for children varied and included 1–17 years, <6 years, <5 years, <4 years, <3 years, <2 years, and <1 years, which makes direct comparison challenging.

Table 7 indicates that of the 72 studies including prevalence of foodborne pathogens among children, they included data regarding *L. monocytogenes* (*n*=12); Salmonella (*n*=34); Campylobacter (*n*=22); *E. coli* (*n*=21), and norovirus (*n*=3).

Table 7. Prevalence of foodborne pathogens among children in reviewed studies (*n*=72) (*L. monocytogenes* *n*=12; Salmonella *n*=34; Campylobacter *n*=22; *E. coli* *n*=21; norovirus *n*=3).

Pathogen	Prevalence data (percentage of cases that were reported among children)
L. monocytogenes	1% of bacteraemia cases in US were aged 1-17 years (Silk *et al.*, 2012) 4% of cases in Latvia were <6 years (Berzins *et al.*, 2009) 18% of cases in Italy were <5 years (Colarusso *et al.*, 2022)
Salmonella	27%, 36%, 41% cases in US were aged <5 years (Akil, 2021; Boore *et al.*, 2015; Li *et al.*, 2021) 31% of cases in the Netherlands were aged <5 years (Doorduyn, 2006) 38% of cases in Poland were aged <5 years (Milczarek *et al.*, 2022; Milczarek *et al.*, 2021) 48 – 52% of cases in Italy were aged <5 years (Colarusso *et al.*, 2022; Sadkowska-Todys & Czarkowski, 2015). 52% of cases in Spain were aged <5 years (Sala Farre *et al.*, 2015)
E. coli	23% and 45% of cases in England and Wales were aged 1-4 years and <15 years, respectively (Adams *et al.*, 2016) 24% and 27% of cases in US were aged 0-4 years and 5-17 years, respectively (Hadler *et al.*, 2018) 25% of cases in Ireland and UK were aged 0-4 years (Rodwell *et al.*, 2022) 25% of cases in the Netherlands were aged 0-4 years (Duynhoven *et al.*, 2002) 40% of cases in England were aged 0-5 years (Rodwell *et al.*, 2023) 40% of cases in Ireland were aged 0-5 years (Cleary *et al.*, 2021) 62% of cases in France were aged <3 years (Jones *et al.*, 2023) 77% of cases in Switzerland were aged <10 years (Kappeli *et al.*, 2011)
Campylobacter	56% of cases in Italy were aged <5 years (Colarusso *et al.*, 2022) 70% of cases in Poland were aged 0-4 years (Gordat *et al.*, 2021) 74% of cases in Spain were aged <5 years (Sala Farre *et al.*, 2015)
Norovirus	11% of cases in Italy were aged <5 years (Pagani *et al.*, 2018)

L. monocytogenes among children

Of the 166 listeriosis cases reported between 2012 – 2022 in Scotland, 4% were aged 0-4 years (Public Health Scotland, no date) (Table 2).

Prevalence of listeriosis among children was only included in 12 of the reviewed studies, as indicated in Table 7. These studies reported that prevalence, like that observed in Scotland, were low among children with 1% of bacteraemia cases in the

US among children aged 1-17 years (Silk *et al.*, 2012) and 4% of all listeriosis cases in Latvia among children aged <6 years (Berzins *et al.*, 2009). Wilking *et al.* (2021) reported that listeriosis among adolescents and children (other than newborns) in Germany is rare. Whereas data from Italy suggested 18% of listeriosis cases were among children aged <5 years (Colarusso *et al.*, 2022).

As indicated in Table 5, the incidence rates of listeriosis among children ranged between 0.28/100,000 for children aged <5 years in Italy (Colarusso *et al.*, 2022), whereas in the US rates of 1.7/100,000 for children aged <5 years (Barkley *et al.*, 2016) and 1.9/100,000 for children aged <1 year (Vugia *et al.*, 2002) were reported.

Salmonella among children

The proportion of laboratory reports per age band varied little between 2013 and 2017, with the 0-4 age band consistently recording the highest proportion. Of the 3,726 laboratory confirmed cases of Salmonella during the 4-year period, 14% were among children aged 0-4 years, this was the highest proportion by age band. The 5-9 years and 10-14 years age bands were much lower with 5% and 4% of cases respectively (Public Health Scotland, Unpublished-d).

In Scotland, the hospitalisation proportion was higher in children aged 0-4 years (24%) and 5-9 years (22%) compared to older children aged 10-14 (13%) and 15-19 years (14%). The rate for Salmonella in Scotland was highest in the 0-4 age band with a rate of 38.3 per 100,000 for males and 33.4 per 100,000 for females (Public Health Scotland, Unpublished-d)

Salmonella was the pathogen most frequently associated with children, with 34 studies providing data regarding salmonellosis among children as indicated in Table 7. The incidence of Salmonella was reported to be highest among children aged <5 years (Crim *et al.*, 2014). The proportion of all Salmonella cases that occurred among children aged <5 years ranged from 27% in the US (Boore *et al.*, 2015) to 52% in Spain (Sala Farre *et al.*, 2015). It was estimated that 10% of illnesses, 20% of hospitalisations and 8% of deaths from Salmonella in the US were among children aged <5 years (Scallan *et al.*, 2013).

The incidence rate of Salmonella in the reviewed studies varied according to age group, for example the incidence rate among children aged <2 years was 207 per 100,000 (Sadkowska-Todys & Czarkowski, 2015), while children aged <5 years was 45 per 100,000 (Boore *et al.*, 2015) and 98.2 per 100,000 among children aged <14 years (Mughini-Gras *et al.*, 2012).

E. coli among children

In Scotland, 18% of 3,358 laboratory confirmed cases of *E. coli* O157/non-O157 STEC between 2012 – 2023 were among children aged 0-4 years (Public Health Scotland, Unpublished-a). During 2019, STEC infection rates in Scotland were reported to vary across the population, with overall higher rates observed in children aged <5 years. Children aged <16 years accounted for 33% of cases. Children aged

<5 years had the highest rate of *E. coli* O157 infection, 9.0 per 100,000 population and 11.6 per 100,000 population for non-O157 STEC (Public Health Scotland, 2020).

Twenty-one of the reviewed studies included prevalence of *E. coli* among children (Table 7). A number of these studies reported that the highest proportion of *E. coli* cases were among young children (Adams *et al.*, 2016; Cleary *et al.*, 2021; Crim *et al.*, 2014; Gould *et al.*, 2013; Jeffs *et al.*, 2018; Jones *et al.*, 2023; Rodwell *et al.*, 2022; Rodwell *et al.*, 2023; Vrbova *et al.*, 2012). Of *E. coli* cases, prevalence among children aged 0-4 years ranged from 24% in the US (Hadler *et al.*, 2018) and 25% in the Netherlands (Duynhoven *et al.*, 2002) with up to 40% in England (Rodwell *et al.*, 2023) and Ireland (Cleary *et al.*, 2021) among children aged 0-5 years. Data from France reported that 62% of cases were among children aged <3 years (Jones *et al.*, 2023) while data from Switzerland reported that 77% of cases were among children aged <10 years. Reviewed studies suggested that the incidence rate of *E. coli* was significantly higher among the 0-4 age group at 3.90 per 100,000 population (95% 3.21-4.58) than any other age group (Adams *et al.*, 2019).

Campylobacter among children

A total of 30,196 confirmed cases of Campylobacter were reported in Scotland between 2013 – 2017, of which 5% were among children aged 0-4 years, fewer were reported among children aged 5-9 years (2%) and 10-14 years (2%) (Food Standards Scotland, 2020a). The hospitalisation rates for Campylobacter in Scotland among children aged 0-4 years was 18%, 5-9 years was 15% and 10-14 and 15-16 years were 11% (Food Standards Scotland, 2020a).

Research from Scotland suggested that the 5-14 years age group was found to have the greatest exposure to Campylobacter risk factors, the 0-4 years age group had the greatest number of cases and the 5-14 years age group the least, indicating that greater exposure does not necessarily result in higher disease incidence. This suggests that those aged 0-4 years are more susceptible to infection due to low immunity or due to behavioural factors (MacRitchie *et al.*, 2013).

Of the reviewed studies, 22 included data regarding campylobacteriosis among children. Most studies reported incidence of Campylobacter to be highest among children aged 0-4 years (Baker *et al.*, 2007; Colarusso *et al.*, 2022; Crim *et al.*, 2014; Doorduyn *et al.*, 2010; Gordat *et al.*, 2021; Jeffs *et al.*, 2018, 2019; John *et al.*, 2022; OzFoodNet Working, 2004, 2012; Sala Farre *et al.*, 2015; Sorokin *et al.*, 2007; Spencer *et al.*, 2012; Vrbova *et al.*, 2012; Vugia *et al.*, 2002), with prevalence data indicating 56-74% of Campylobacter cases in various European countries to be among children <5 years (Colarusso *et al.*, 2022; Gordat *et al.*, 2021; Sala Farre *et al.*, 2015) (Table 7).

Reported hospitalisation rates for campylobacter were highest for children aged <1 year (Baker *et al.*, 2007; Jeffs *et al.*, 2019). The incidence rate of campylobacteriosis for the 0-4 years age group was reported to be twice as high as almost all other age groups (Spencer *et al.*, 2012), with incidence rates of Campylobacter among children aged <5 years varying from 1.86 per 100,000 in Italy (Colarusso *et al.*, 2022) to 578 per 100,000 in New Zealand (Baker *et al.*, 2007).

Norovirus among children

As indicated in Table 2, a fifth (20%) of the 15,725 laboratory confirmed cases of norovirus between 2012 – 2023 were among children aged 0 – 4 years (Public Health Scotland, Unpublished-c).

Only three of the reviewed studies provided insight into prevalence of norovirus among children. These studies reported that the incidence of norovirus was "high" among children aged <3 years in Lithuania, with infections reported to be 6 times higher than among aged 4-6 years (Milisiunaite *et al.*, 2010), 11% of norovirus cases in Italy were among children aged <5 years (Pagani *et al.*, 2018) and the highest incidence was reported among children aged <5 years with community incidence at a rate of 152.2 per 1,000 person-years in the US (Grytdal *et al.*, 2016).

4.1.5. Older adults as a clinically vulnerable group

Ageing and senescence of the immune system makes older adults vulnerable to infections (Chen *et al.*, 2016). An ageing immune system is less efficient in its response, increasing the risk of severe outcomes and invasive disease in older individuals (Parry *et al.*, 2013; Scallan *et al.*, 2015a, 2015b). Ageing is associated with progressive deterioration of the immune system and other organs, eventually leading to organ failure and death (Weyand & Goronzy, 2016). Ageing affects innate immunity; however, the underlying molecular events are not well understood (Goronzy & Weyand, 2013). Much more is known about adaptive immunity. The immune system is prone to ageing due to its intense production of several metabolites (e.g. antibodies, cytokines) and cell-surface molecules (e.g., stimulatory, and inhibitory receptors and ligands) in response to antigens. This requires rapid and intense proliferation of immune cells, making the immune system highly susceptible to ageing. T-cells, that have the highest proliferative potential in the body and, with a survival span of several decades, are subject to wear-and-tear damage (Weyand & Goronzy, 2016). The effects of ageing immunity manifests in slower production of T-cell and B-cells by immune system organs, causing the decline in immune system function (Montecino-Rodriguez *et al.*, 2013).

As the immune system progresses through senescence, older adults become more vulnerable to foodborne infections. Several studies have specifically examined risk factors for infection in this population (Institute of Medicine Division of Health Promotion and Disease, 1992; Liljas *et al.*, 2022). The risks of severe outcomes and incidence of invasive disease (Parry *et al.*, 2013) resulting in complications and mortality grow with age (Scallan et al., 2015b). While ageing related changes are unavoidable, their timing varies widely among individuals. At the same time, the incidences of chronic inflammatory diseases (e.g. cardiovascular disease, diabetes, cancers, etc.) increase. The underlying conditions among older adults, and the medications used to treat or manage the diseases, make them further vulnerable to

foodborne illnesses (Gavazzi *et al.*, 2004). In high-income countries, the greatest increases in the prevalence of multimorbidity commonly occur in two periods: between the ages of 50 and 60 years, and in advanced old age (≥70 years) (WHO, 2015). Due to complex overall ageing processes involved, immune system senescence occurs at a different pace in individuals. However, in the literature, 60 is frequently cited (WHO, 2015) as the age when the immune system is considered senescent in most ageing adults. The age of 65 is commonly cited in the literature describing foodborne illness infection, however, this cut-off may not be aligned with the physiology of the ageing immune system.

Ageing individuals are increasingly likely to experience multimorbidity. Specifically, several GI diseases become more common, including oesophageal and stomach conditions (e.g. gastroesophageal reflux disease, chronic atrophic gastritis, *Helicobacter pylori* infection, etc.) (Bhutto & Morley, 2008). Management of these conditions that occur more frequently in ageing adults, especially individuals older than 65, require chronic medications that reduce levels of stomach acid as a side effect (Dumic *et al.*, 2019).

Older adults in Scotland

Census data report there are over one million people aged 65 and over in Scotland, accounting for 20% of the population (Scotland's Census, 2023). Data specifically regarding those aged ≥65 years were available for the five pathogens of interest.

Prevalence of foodborne illness among older adults.

Data on the prevalence of all five foodborne pathogens among the older adult population in Scotland were available. Of the 185 reviewed studies, 84 presented data regarding older adults, these included various age category classifications including >50, >60, >65 and >75 years. These studies included data regarding the five pathogens of interest, *L. monocytogenes* (*n*=49); Salmonella (*n*=21); Campylobacter (*n*=9); *E. coli* (*n*=11), and norovirus (*n*=2). The prevalence of these pathogens among older adults are included in Table 8.

Table 8. Prevalence of foodborne pathogens among older adults in reviewed studies (*n*=84) (*L. monocytogenes* *n*=49; Salmonella *n*=21; Campylobacter *n*=9; *E. coli* *n*=11; norovirus *n*=2).

Pathogen	Prevalence data (percentage of cases reported among older adults)
L. monocytogenes	30% of cases in Portugal were aged >65 years (Almeida *et al.*, 2006) 65 – 67% of cases in Italy were aged >65 years (Gori *et al.*, 2020) 71% of notifications in Australia were aged >65 years (Leung *et al.*, 2018). 71% of cases in Norway were aged >60 years (Antal *et al.*, 2007). 74% of cases in Australia were aged >60 years and 40% were aged >75 years (Dalton *et al.*, 2011). 76% of cases in Germany were aged >65 years (Wilking *et al.*, 2021) 76% of cases in Australia were aged >60 years (OzFoodNet Working, 2012) 76% of cases in England were aged >60 years (Gillespie *et al.*, 2010)
Salmonella	9% of cases in Denmark were aged >65 years (Gradel *et al.*, 2008). 12% of cases in Spain were aged >65 years (Sala Farre *et al.*, 2015) 16% of cases in US were aged >60 years (Akil, 2021; Tumuhairwe *et al.*, 2008) 17% of cases in Italy were aged >65 years (Graziani *et al.*, 2015). 65 – 67% of cases in Poland were aged >60 years (Milczarek *et al.*, 2021)
E. coli	7% of cases in Switzerland were aged >60 years (Kappeli *et al.*, 2011) 10% of cases in US were aged >65 years (Hadler *et al.*, 2018) 11% of cases in US were aged >60 years (Gould *et al.*, 2009) 17% of cases in Ireland were aged >65 years (Cleary *et al.*, 2021)
Campylobacter	3% of cases in Spain were aged >65 years (Sala Farre *et al.*, 2015) 14% of cases in US were aged >75 years (Armed Forces Health Surveillance, 2014)
Norovirus	22% of cases were aged ⩾69 years (Pagani *et al.*, 2018)

L. monocytogenes among older adults

As indicated in Table 2, the Listeria surveillance data obtained from Public Health Scotland indicated that 68% of the 166 laboratory confirmed cases of listeriosis between 2012 – 2022 were aged ≥65 years; the 75-79 age band accounted for 18% of the cases. Although data show an increase in prevalence after the age of 65

years, data indicate that 7.2% of listeriosis cases were among people aged 60 – 64 years, compared to 3.6% among the 55 – 59 years age band. Of the 10 known deaths believed to be associated with listeria, nine were among those aged over 65 (Public Health Scotland, no date).

A total of 47 studies included data detailing listeriosis among older adults. This was the highest number of studies referring to a specific clinically vulnerable group and specific pathogen. Numerous studies reported that the median age of listeriosis cases were >65 years (69 years (Preußel *et al.*, 2015); 71 year (Bennion *et al.*, 2008; Gori *et al.*, 2020; Vallejo *et al.*, 2022); 72 years (Gillespie *et al.*, 2009); 73 years (Charlier *et al.*, 2017) and 75 years (Suominen *et al.*, 2023)).

Prevalence data, as illustrated in Table 8 ranged from 30% of cases among people aged >65 years in Portugal (Almeida *et al.*, 2006) to 76% of cases in Germany (Wilking *et al.*, 2021), Australia (OzFoodNet Working, 2012) and England (Gillespie *et al.*, 2010) among older adult age groups. Furthermore, the mortality rate associated with listeriosis increased with age, those aged 60-69 years, the mortality rate was 30%; among those aged 70-79 years, it was 32%; and those aged 80+, it was 36% (Scobie *et al.*, 2019).

The incidence rate of listeriosis in Finland was reported to be 11-fold greater in those aged ≥75 years compared to other age groups (Suominen *et al.*, 2023). Similarly, in England, Listeria incidence rate peaked in adults ≥60 years, which were 4.4 times the rate compared with children 0-4 years old (Scobie *et al.*, 2019).

It was reported that the increased incidence of listeriosis among individuals ≥60 years old in England and Wales between 2001 and 2007 occurred in those with cancer or other conditions whose treatment included acid-suppressing medication (Gillespie *et al.*, 2009).

Salmonella among older adults

Of the 3,726 laboratory confirmed cases of non-typhoidal Salmonella in Scotland over the period 2013-2017, 15% were among those aged ≥65 years (Table 2) (Public Health Scotland, Unpublished-d). Although data suggest a peak in young adults, an increase was observed in middle aged adults and a decline in older adults. Mean length of stay increased with age particularly among those aged over 74 years, with the highest proportion of hospitalisations among those aged ≥80 years (Public Health Scotland, Unpublished-d). The cost burden on hospitals from confirmed Salmonella cases increases with age due to the higher rate of hospitalisation and a longer hospital stay among the older adult cases. This increased length of stay may be associated with other conditions (Public Health Scotland, Unpublished-b).

Twenty-one studies included data regarding prevalence of Salmonella among older adults. Similar to data from Scotland, these studies suggested that between 9 – 17% of salmonellosis cases were among older adults (Akil, 2021; Gradel *et al.*, 2008; Graziani *et al.*, 2015; Sala Farre *et al.*, 2015; Tumuhairwe *et al.*, 2008). Conversely, one study suggested that 65 – 67% of salmonellosis cases in Poland were among those aged >60 years, however it was suggested that these were parenteral salmonellosis which occur outside of the intestine (Milczarek *et al.*, 2021) (Table 8).

Incidence rate in Australia increased from 2.4 per 100,000 for those aged 60-69 years to 5.2, and 4.8 per 100,000 for age groups 70-79 years and 80+ (Parisi *et al.*, 2019). Although the reviewed studies do not suggest that older adults are disproportionally included in prevalence of Salmonella, older adults did have the highest proportion of Salmonella infections requiring hospitalisation (Wilson *et al.*, 2018). The percentage hospitalised for Salmonella and the percentage who died from Salmonella was higher among adults aged ≥65 years than among children aged <5 years or people aged 5-64 years (Scallan et al., 2015a).

There is a need to consider underlying conditions among the older adult groups, Turgeon *et al.* (2017) reported that among those aged ≥60 years that were hospitalised with non-typhoidal Salmonella, 60% were also diagnosed with at least one of four prevalent chronic diseases these being cardiovascular diseases, diabetes, arthritis, and cancer.

E. coli among older adults

Fourteen percent of the 3,358 laboratory confirmed cases of *E. coli* between 2012 – 2023 in Scotland were aged ≥65 years (Table 2) (Public Health Scotland, Unpublished-a). Age distribution data of non-O157 STEC in Scotland during 2019 reported that 12% of cases were ≥65 years and 13% of *E. coli* O157 cases were ≥65 years (Public Health Scotland, 2020).

Data from the 11 of the 138 reviewed studies that provided information regarding *E. coli* among the over 60 population, suggested that between 7 – 17% of cases were >60 years (Cleary *et al.*, 2021; Gould *et al.*, 2009; Hadler *et al.*, 2018; Kappeli *et al.*, 2011). As with Salmonella, the percentage hospitalised for *E. coli* O157 and the percentage who died was higher among adults aged ≥65 years than among children aged <5 years or people aged 5-64 years (Scallan et al., 2015a) (Table 8).

As indicated in Table 5, the incidence rate for *E. coli* among people aged ≥60 years were available for England and Wales (0.98 cases per 100,000 population) (Adams *et al.*, 2016) and the US (0.22 cases per 100,000 population) (Gould *et al.*, 2013), these studies reported that crude incidence of *E. coli* infections decreased with increasing age as incidence was lowest among this age group compared to others.

People aged ≥65 years were reported to be disproportionately affected by E. coli in Ireland, accounting for 16.6%, compared with 11.7% for the national population (Cleary *et al.*, 2021)

Campylobacter among older adults

Between 2013 – 2017, 23% of 30,196 confirmed Campylobacter cases in Scotland were aged ≥65 years. Although those aged 60 – 69 years, 70 – 79 years, and 80+ years accounted for 16%, 11% and 5% of cases respectively, the highest percentage of cases was in the 50 – 59 age group (18%) (Food Standards Scotland, 2020a).

The hospitalisation rate among older adults in Scotland increased with age (60-64 years 12%; 65-69 13%; 70-74 years 19%; 75-79 years 24%, and ≥80 years 33%), furthermore the mean length of stay also increased with age.

Severity of illness was greater among those of older age. Among the 101 cases admitted to an intensive care or high dependency unit for a Campylobacter related condition, 50% were aged ≥65 years (Food Standards Scotland, 2020b) and the mean age of 67.7 years for cases with a severe outcome was >20 years above the mean age for all Campylobacter cases (46.2 years). This may be attributed to the higher rates of underlying medical conditions among the older population. Over the 5-year period, 12 cases died with *Campylobacter enteritis* with a mean age of 75.5 years (Food Standards Scotland, 2020a, 2020b).

Nine studies discussed older adults in relation to Campylobacter, as indicated in Table 2, between 3% of all Campylobacter cases in Spain were aged ≥65 years (Sala Farre *et al.*, 2015) and up to 14% of cases in the US were aged ≥75 years (Armed Forces Health Surveillance, 2014) (Table 8).

In the US, although among adults aged ≥65 years, the rate of infection decreased with age for Campylobacter, the percentage hospitalised for Campylobacter and the percentage who died from Campylobacter was higher among adults aged ≥65 years than among children aged <5 years or people aged 5-64 years (Scallan et al., 2015a). Data from New Zealand also indicated a peak in hospitalisations from Campylobacter among people aged ≥70 years (Baker *et al.*, 2007) The case fatality rate from Campylobacter in the US was highest in persons aged ≥50 years (0.4%) (Vugia *et al.*, 2009).

Norovirus among older adults

Data obtained from Scotland regarding the 15,725 confirmed norovirus cases between 2012 and 2023, reported that 60% of cases were among those aged ≥60 years.

There was a lack of comparable data globally, with only two of the reviewed studies including prevalence of norovirus among older adults. These studies suggested that of 37 community acquired cases of norovirus in Italy, 22% were among people aged ≥69 years (Pagani *et al.*, 2018) and that the community incidence rate of norovirus in the US was reported to be 75.8 per 1,000 person-years (Grytdal *et al.*, 2016).

4.1.6. People using proton pump inhibitors (PPI) as a clinically vulnerable group

Gastric acid (hydrochloric acid) is produced by gastric glands in the stomach wall and released into the stomach. Gastric acid provides the first line of protection against foodborne infections in humans (Smith, 2003). It plays a critical role in the digestion of food by activating pepsinogen and denaturing proteins from food, facilitating the absorption of calcium and iron, and by inhibiting infectious bacteria from reaching the intestine (Martinsen *et al.*, 2005). Studies *in vitro* and *in vivo* have shown that gastric juice kills bacteria within 15 to 30 minutes when the pH is at a normal level (pH <3) (Tennant *et al.*, 2008). If the pH is raised above 4.0, bacterial overgrowth occurs (Giannella *et al.*, 1972).

Hypochlorhydria, is a condition when gastric acid levels are low in the stomach resulting in an elevated pH (4<pH<7) (Hedberg, 2022) and characterized by increased susceptibility to pathogen overgrowth. Animal experiments have shown enhanced survival of foodborne human pathogens including *Salmonella enterica* serovar Typhimurium, *Yersinia enterocolica*, and *Clostridium perfringens* after the passage through the stomachs of hypochlorhydric mice (Tennant *et al.*, 2008), demonstrating that gastric acid provides a barrier even from highly acid resistant Yersinia strains of foodborne pathogens and Clostridium spores (Hedberg, 2022). Hypochlorhydria can be acquired as a side effect of gastric surgery or through chronic use of certain medications (Haastrup *et al.*, 2018).

Although older adults are often thought to be more prone to foodborne illness due to the decreased level of gastric acid, hypochlorhydria does not seem to be directly related to old age but rather to underlining conditions that increase in prevalence with age (Feldman *et al.*, 1996). In research studies investigating age dependence of stomach pH, gastric acid output rates in older adults (>65 years of age) were similar to young (18–34 years) and middle-aged (35–64 years) groups after adjustments for histology, *H. pylori* infection, and other conditions (Soenen *et al.*, 2016). The decline

in acid secretion in older adults is primarily linked to a higher prevalence of gastrointestinal problems among ageing individuals, especially those aged over 65 years. Gastrointestinal disorders that increase in incidence with age include gastroesophageal reflux disease, chronic atrophic gastritis, and *H. pylori* infections. These disorders result in a slower return to baseline levels after pH-level disruption, and increased probability of pathogen passage to the intestines (Feldman *et al.*, 1996; Russell *et al.*, 1993). Management of these conditions often requires chronic medications that reduce levels of stomach acid as a side effect (Haastrup *et al.*, 2018).

Proton pumps are enzymes in the stomach lining that help make acid to digest food. The proton pump (H+/K+-ATPase) is the final common pathway for acid secretion in gastric cells, and inhibition of the pump blocks acid secretion (Waller & Sampson, 2018). Proton pump inhibitors (PPIs) are a class of medications used to treat a wide variety of pathologies related to the stomach's acid production (Ahmed & Clarke, 2023). For example, Omeprazole is prescribed to help reduce the amount of acid the stomach makes, and is widely used to treat indigestion, heartburn, acid reflux, and to prevent and treat stomach ulcers (NHS, 2021). While the acidic environment of the stomach serves as a chemical barrier against bacterial infection, PPI use is associated with increased enteric foodborne infections (Ahmed & Clarke, 2023). A single dose of a PPI inhibits acid production by up to 90% for approximately 24 hours (Waller & Sampson, 2018). Although the exact mechanism for the increased infection risk is still under investigation, it is believed that the decreased acidic environment of the stomach leads to bacterial overgrowth thus increasing the risk of bacterial aspiration and changes in the gut microbiome (Ahmed & Clarke, 2023; Godman *et al.*, 2018).

PPIs are commonly prescribed to ageing adults (Dumic *et al.*, 2019). A systematic review of PPI utilisation reported most frequent use in individuals 65 years and older (37.1% of total users), followed by the young to middle aged group (≤ 49 years old: 34.7% of total users), females (56.1%), and those of white ethnicity (75%) (Shanika *et al.*, 2023). The prescription of PPI medication, or over-the-counter use completely impairs gastric acid secretion leading to medication induced hypochlorhydria (Hurwitz *et al.*, 1997). Increased risk of infection over time has been demonstrated among people using PPIs (Yibirin *et al.*, 2021). Several infections have been linked to ongoing use of this group of medications, however, long-term susceptibility to infections due to past exposures to PPIs has been reported. Increased prevalence of *Clostridium difficile* infections has been shown in individuals with current and past use of PPIs. PPI use is a known risk factor for kidney, urinary, respiratory, and other infections. PPI use also increases the risk of fractures (Thong *et al.*, 2019), dementia (Ortiz-Guerrero *et al.*, 2018), cardiovascular disease (Manolis *et al.*, 2020), and may lead to several malnutrition disorders (e.g. Vit B-12 deficiency, hypomagnesemia) due to impaired nutrient absorption (Mumtaz *et al.*, 2022).

With ageing populations, the increasing prevalence of chronic diseases, and polypharmacy (simultaneous use of multiple medicines by an individual for their conditions), PPIs have become one of the most prescribed medicines in developing countries due to their effectiveness versus Histamine Type-2 (H2) receptor antagonists/blockers (Godman *et al.*, 2018).

Increased use of PPI medications among children has been documented in many developed countries (Lassalle *et al.*, 2023). In France, 6.1% of children under 2 years of age used PPIs in 2019 (Taine *et al.*, 2021). Prevalence of PPI use among children in Denmark in 2020 was 4.6%, tripling in the last two decades (Aznar-Lou *et al.*, 2019). Similarly in New Zealand, PPI prescriptions increased from 2.4% to 5.2% between 2005 and 2012 (Blank & Parkin, 2017).

PPI usage in Scotland

In Scotland, a three-fold increase in PPI use was seen between 2001 and 2017 (Godman *et al.*, 2018). During 2019/20 and 2020/21, omeprazole was the most commonly prescribed item in NHS Scotland, accounting for a total of 4.2 million items annually (Public Health Scotland, 2022).

PPIs are reportedly overprescribed (Forgacs & Loganayagam, 2008) and are often taken for longer than needed (Farrell *et al.*, 2022). It has been suggested that 41% of older individuals in Scotland are prescribed PPIs, 86% of which were inappropriate overprescribed PPIs (Jarchow-MacDonald & Mangoni, 2013).

Prevalence of foodborne illness among people using PPIs

Among the 138 reviewed studies, 12 included data detailing the association between PPI use and prevalence of foodborne illness, of which five included listeriosis, three included salmonellosis and four included campylobacteriosis. No studies included *E. coli* or norovirus (Table 9).

Table 9. Prevalence of foodborne pathogens associated with proton pump inhibitor use in reviewed studies (*n*=12) (*L. monocytogenes* *n*=5; Salmonella *n*=3; Campylobacter *n*=4; *E. coli* *n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were associated with proton pump inhibitor use)
L. monocytogenes	16% cases in Germany prescribed PPIs (Preußel *et al.*, 2015) 16% CNS and 13% Bacteraemia cases in UK used PPIs (Gillespie *et al.*, 2009) 50% cases in Finland prescribed PPIs in the 90 days preceding infection (Suominen *et al.*, 2023)
Salmonella	9% of cases in the Netherlands associated with PPI use (Doorduyn, Van Den Brandhof, *et al.*, 2006)
E. coli	No data available
Campylobacter	8% of cases in the Netherlands were issued PPI prescriptions (Bouwknegt *et al.*, 2014) 10% of cases in the Netherlands associated with PPI use and 2% associated with H2 antagonists (Doorduyn, Van Den Brandhof, *et al.*, 2006) 10% of cases self-reported recent use of acid-suppressing medication (Tam *et al.*, 2009) 13% of cases in Australia were attributable PPI use in the 28 days preceding infection (Cribb *et al.*, 2022)
Norovirus	No data available

L. monocytogenes among PPI users

Data regarding the association between PPI use in Scotland and cases of listeriosis were not available. Five of the reviewed studies provided information detailing PPI use among people with listeriosis. The reviewed studies suggested that prescribed PPIs were associated with an increased risk of listeriosis, with 16 – 50% of cases in Europe reported to be among people prescribed PPIs prior to listeriosis infection (Gillespie *et al.*, 2009; Preußel *et al.*, 2015; Suominen *et al.*, 2023) (Table 9).

A population-based case-control study using Danish health registries established that the adjusted odds ratio (OR) for development of listeriosis with current use of a PPI was 2.81 (95% CI, 2.14-3.69) suggesting that PPI usage <90 days before listeriosis infection was statistically significant, the risk waned with time since last prescription redemption whereas no significant association was found for use of H2 antagonists, (adjusted OR, 1.82 (95% confidence interval, 0.89-3.71)) (Kvistholm Jensen *et al.*, 2017).

Salmonella among PPI users

Of the 3,726 Salmonella cases reported in Scotland, 25% were prescribed PPIs in the 90 days preceding their positive specimen date (Public Health Scotland, Unpublished-d) (Table 2).

Reviewed studies suggested that 9% of cases in the Netherlands were associated with PPI use and 3% of cases were associated with H2 antagonists (Doorduyn, Van Den Brandhof, *et al.*, 2006). Australian data indicated that 23% of salmonellosis-associated hospitalisations had a peptic ulcer disease and/or PPI use listed as an underlying condition (Wilson *et al.*, 2018) (Table 9). Chen *et al.* (2016) reported that among adults aged ≥45 years in Australia, for those taking PPIs the risk of Salmonella infection was 1.9 times higher than for those not taking PPIs.

Campylobacter among PPI users

Data obtained from Scotland indicated that 34% of campylobacteriosis cases were prescribed PPIs in the 90 days preceding infection (Food Standards Scotland, 2020a) (Table 2).

A previous review regarding the campylobacteriosis epidemic in Scotland between 1990–2012 which saw a 75% increase in reported cases that included a 300% increase among older adults and a 50% decrease in young children, suggested that the increase in Campylobacter incidence may be explained by the increase in dispensing, and over-the-counter availability of PPIs with 30% of campylobacteriosis cases among older adults associated with PPI use. It is proposed that as PPI prescribing increases, combined with the growing number of older adults in Scotland, it will likely result in a further increase in cases and hospitalisations of campylobacteriosis associated with PPI use (Strachan *et al.*, 2013).

The reviewed studies indicated that PPI use was attributed to 8 – 13% of cases (Bouwknegt *et al.*, 2014; Cribb *et al.*, 2022; Doorduyn, Van Den Brandhof, *et al.*, 2006). It must also be considered that similar medication can be purchased without a prescription, indeed, data from England reported that 10% of *Campylobacter enteritis* cases self-reported recent use of acid-suppressing medication (Tam *et al.*, 2009). As with salmonellosis, the proportion of campylobacteriosis cases associated with H2 antagonists was lower (2%) than those associated with PPI use (10%) (Doorduyn, Van Den Brandhof, *et al.*, 2006).

It was established that the use of PPIs in the 4 weeks prior to illness was significantly associated with campylobacteriosis (adjusted OR, 2.8, 95% confidence interval, 1.9-4.3) (Cribb *et al.*, 2022). Bouwknegt *et al.* (2014) reported that the effect of PPI prescriptions was greatest amongst the younger age groups and gradually decreased for older age groups despite the larger number of prescriptions in the older groups. For example, of those with campylobacteriosis, 12% were aged <25 years with a PPI prescription, the incidence rate ratio was 1.0, whereas 41% were aged >71 years with a PPI prescription, for which the incidence rate ratio was 0.56.

E. coli and norovirus among PPI users

Data regarding prevalence of PPI use among cases of *E. coli,* and norovirus were not available in data obtained from Scotland or the reviewed studies.

4.1.7. People with rheumatoid arthritis as a clinically vulnerable group

Rheumatoid arthritis is a chronic autoimmune, inflammatory disease characterised by inflammation in the affected parts of the body, commonly joints (Brody, 2012). Estimated global prevalence of rheumatoid arthritis is 0.5-1% (Almutairi *et al.*, 2021). People with rheumatoid arthritis have increased susceptibility to foodborne illness and other infections due to the pathobiology of their disease, characterised by premature ageing of the immune system. Additionally, multiple co-morbidities and immunosuppressive therapy in rheumatoid arthritis have a profound impact on the risk of infections (Listing *et al.*, 2013).

In people with rheumatoid arthritis, ageing of the immune system occurs at an accelerated rate, impairing the host's protection against pathogen invasion and making them susceptible to infections (Li *et al.*, 2018). T-cells, which are most prone to ageing, undergo premature immunosenescence marked by the loss of CD28 and shortening of telomeric sequences. Naïve CD4 T-cells are reprogrammed due to changes in metabolic pathways causing the profound remodelling of the immune system. Clonally expanded CD4+CD28- T-cells that are proinflammatory and tissue destructive accumulate (Li *et al.*, 2018), leading to chronic immunological dysfunctions and premature immunosenescence. Multiple co-morbidities in people with rheumatoid arthritis further exasperate their vulnerability. Chronic diseases such as diabetes, cardiovascular, lung and kidney diseases, malignancies, and other underlying conditions have increased the risk of foodborne illness among people with rheumatoid arthritis. These co-morbidities are more common among people with rheumatoid arthritis compared to the general population (Baillet *et al.*, 2016).

Additionally, rheumatoid arthritis therapy uses multiple immunosuppressive drugs (American College of Rheumatology Subcommittee on Rheumatoid Arthritis Guidelines, 2002) . The risk of infections among people with rheumatoid arthritis will depend on the dose and combination of the treatment they receive (Thomas & Vassilopoulos, 2020). Glucocorticosteroids have been shown to increase

susceptibility to severe infections up to 4-fold in a dose-dependent manner (Youssef *et al.*, 2016). TNF-α inhibitors also increase the risk of serious infection up to 2-fold (Listing *et al.*, 2013). Other potent immunosuppressive drugs include biologics, T-cell blockers, B-cell depleting drugs, and other immunomodulatory agents that all contribute to immunological disfunctions and increased susceptibility.

People with rheumatoid arthritis in Scotland

No single official statistic exists for the prevalence of rheumatoid arthritis in Scotland (The Scottish Inflammatory Diseases and Rheumatology Industry Group, no date). It is difficult to ascertain current levels of prevalence of rheumatoid arthritis in Scotland (Scottish Public Health Network, 2012). In 2012, an estimated 36,835 adults in Scotland had rheumatoid arthritis (Scottish Public Health Network, 2012). In 2018, 44,000 people in Scotland were reported to have rheumatoid arthritis (British Society for Rheumatology & Scottish Society for Rheumatology, 2018). Rheumatoid arthritis is the 23rd most common cause of disease burden in Scotland, with women bearing a larger share (68%) compared to men (32%). Overall, 52% of the total rheumatoid arthritis burden was contributed by individuals aged 35 to 64 years (NHS Health Scotland, 2017), however the prevalence of rheumatoid arthritis increases considerably with age (Scottish Public Health Network, 2012).

Prevalence of foodborne illness among people with rheumatoid arthritis

No data were available from Scotland regarding the prevalence of rheumatoid arthritis as an underlying condition among the five foodborne pathogens of interest. Of the 138 reviewed studies, eight included such data, six of which referred to listeriosis, and two referred to salmonellosis (Table 10).

Table 10. Prevalence of foodborne pathogens among people with rheumatoid arthritis in reviewed studies (*n*=8) (*L. monocytogenes* *n*=6; Salmonella *n*=2; Campylobacter *n*=0; *E. coli* *n*=0; norovirus *n*=0)

Pathogen	Prevalence data (percentage of cases that were reported to be among people with rheumatoid arthritis)
L. monocytogenes	2% of cases in France had rheumatoid arthritis (Goulet *et al.*, 2012) 3 – 19% of cases in Australia had rheumatological conditions (Dalton *et al.*, 2011; Leung *et al.*, 2018) 6% of cases in England received drugs for rheumatic diseases and gout (Mook *et al.*, 2013) 13% of cases in Finland had rheumatological conditions (Suominen *et al.*, 2023) 18% of cases in Germany had rheumatoid arthritis (Preußel *et al.*, 2015)
Salmonella	Prevalence data not included in reviewed studies
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among people with rheumatoid arthritis

No data were available from Scotland detailing the proportion of listeriosis cases with rheumatoid arthritis listed as an underlying condition or reported to be receiving medication for a rheumatological condition. Nevertheless, data were available from reviewed studies. As indicated in Table 10, prevalence of rheumatoid arthritis among cases of listeriosis ranged from 2% in France (Goulet *et al.*, 2012) up to 19% in Australia (Leung *et al.*, 2018). No further data regarding the proportion of hospitalisations or deaths were available and incidence rates were not presented.

Salmonella among people with rheumatoid arthritis

No data were available from Scotland detailing the proportion of salmonellosis cases with rheumatoid arthritis listed as an underlying condition or reported to be receiving medication for a rheumatological condition. A study detailing hospitalisations associated with salmonellosis among people aged ≥60 years in Canada reported that rheumatoid arthritis was one of four chronic underlying conditions among 60% of such hospitalisations (Turgeon *et al.*, 2017). In a study by Cummings and colleagues regarding salmonellosis mortality in the US between 1990 and 2006, it was reported that 0.9% of Salmonella related deaths had rheumatoid arthritis listed as a comorbid condition, in comparison to 0.27% of matched control non-Salmonella related deaths, thus giving a matched OR of 3.43; (95% CI, 1.35–8.71) (Cummings *et al.*, 2010).

E. coli, Campylobacter and Norovirus associated with rheumatoid arthritis

Data detailing prevalence of rheumatoid arthritis among cases of *E. coli,* Campylobacter and norovirus were not available from Scotland or in the reviewed studies (*n*=138).

4.1.8. People with diabetes mellitus as a clinically vulnerable group

Diabetes is a chronic inflammatory disease characterised by high blood glucose levels and the inability to produce or efficiently utilise insulin (Alberti & Zimmet, 1998). The susceptibility of individuals with diabetes to infections has been well documented. Increased risk of lower respiratory tract infections, urinary tract infections, skin, and soft tissue infections in people with diabetes have been reported in several studies (Berbudi *et al.*, 2020; Kornum *et al.*, 2007). Diabetes is cited as a predisposing factor for listeriosis, salmonellosis, and other foodborne infections (Hu *et al.*, 2013; Steinbrecher *et al.*, 2023). Moreover, the outcome of infections is often more severe with poor treatment responses and slow recovery (Leibovici *et al.*, 1996). In individuals with diabetes, both innate (dysfunction of neutrophils and macrophages) and adaptive immune system cells (T-cells) dysfunction contribute to a weak immune response against invading pathogens.

The mechanisms behind the impairment of the immune system in diabetes are multi-layered and have been only partially elucidated. In diabetes, the immune system is impaired due to high glucose levels, and due to insulin deficiency (Chávez-Reyes *et al.*, 2021). Hyperglycaemia in individuals with diabetes attenuates the effectiveness of white blood cells against pathogens (Tessaro *et al.*, 2017). Suppression of cytokine secretion (IL-B1, IL-1, IL-6, IL-17A) by monocytes isolated from individuals with diabetes (Bradshaw *et al.*, 2009), and by healthy-donor monocytes exposed to elevated glucose levels (Torres-Castro *et al.*, 2016), has been shown *in vitro*. Suppression of cytokines impairs antibody production and T-cell development by the immune system (Tanaka *et al.*, 2014), leading to a weak response against invading human pathogens due to hyperglycaemia (Spindler *et al.*, 2016). Furthermore, the loss of IL-12, IFN-γ and TNF-α by T-cells has been reported (Price *et al.*, 2010), indicating the impaired capacity of immune cells to control bacterial growth during infection (Tessaro *et al.*, 2017), leading to diminished leukocyte activity. Thus, high

glucose levels lead to a slow and ineffective immune response. The impact of insulin deficiency on immune system activity against pathogens has not been widely studied. A lack of insulin has been shown to cause low TNF-α and IL-6, affecting leukocyte function against pathogens (Ferracini *et al.*, 2010). Dysfunction of macrophages, neutrophils, and natural killer cells in diabetes have been reported (Berrou *et al.*, 2013).

Neuropathy in individuals with diabetes has been shown to affect the gastrointestinal tract, sensory innervation, and digestion among individuals with diabetes (Azpiroz & Malagelada, 2016). Due to nerve damage, sensory and reflex controls are impaired which causes disorders in gut motor function. Different neural pathways can be affected resulting in different clinical manifestations (Azpiroz & Malagelada, 2016). Inadequate stomach contractions and delayed emptying cause heartburn, nausea, and vomiting. In the intestine, impaired contractions may lead to diarrhoea, constipation, or distension. These disruptions to the functioning of the gut affect mucosal barriers and the gut microbiome, making individuals with diabetes more prone to pathogen penetration and infections with opportunistic pathogens (Bielka *et al.*, 2022). In addition, mechanistic interactions between the microbiome and the host innate immune system have been shown to be mediated by TLR4-LPS signalling, pointing to disruption of the microbiome (Zheng *et al.*, 2020). Since the gut microbiome regulates oxygen availability via butyrate production, thus protecting against the proliferation of pathogens such as *E. coli* and *Salmonella* spp. (Khan *et al.*, 2021), its dysbiosis contributes to the additional layer of susceptibility to foodborne infections in individuals with diabetes.

Gestational diabetes mellitus affects 5–10% of pregnancies worldwide and is associated with immune dysregulation caused by changes in maternal immune cell activity (McElwain et al., 2021). It increases systemic inflammation and insulin resistance, disrupting immune responses (Sifnaios et al., 2019). This reduces infection resistance in neonates (Wang & Xue, 2023) and poses a significant infection risk for pregnant individuals (Yefet et al., 2023).

People with diabetes in Scotland

The Scottish Diabetes Survey reported that there were 339,018 people with diabetes in Scotland at the end of 2022. This represents 6.2% of the Scottish population (NHS Scotland & Scottish Diabetes Data Group, 2023). Type 1 diabetes accounted for 10.5% of all cases and type 2 diabetes accounted for 87.8% of all cases of diabetes in Scotland (NHS Scotland & Scottish Diabetes Data Group, 2023). Other forms of diabetes (e.g. gestational diabetes, latent autoimmune diabetes of adults, monogenic diabetes, maturity onset diabetes of the young, neonatal diabetes) are less common (1.7%) (NHS Scotland & Scottish Diabetes Data Group, 2023). It is estimated that a further 49,000 people have undiagnosed type 2 diabetes and that at least 620,000 people in Scotland are at high risk of developing type 2 diabetes (NHS Research Scotland, 2023). By 2035, it is estimated that more than 480,000 people in Scotland will be living with diabetes (Diabetes UK, 2024).

Prevalence of foodborne illness among people with diabetes

Data detailing the prevalence of diabetes among foodborne illness in Scotland were available for three of the five pathogens of interest, *L. monocytogenes*, Salmonella and Campylobacter (Table 2). A total of 20 studies from the 138 reviewed included such data, of which 19 included listeriosis (Table 11).

Table 11. Prevalence of foodborne pathogens among people with diabetes in reviewed studies (*n*=20) (*L. monocytogenes n*=19; Salmonella *n*=1; Campylobacter *n*=0; *E. coli n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that had diabetes listed as an underlying condition)
L. monocytogenes	7 – 8% of cases in Italy (Gori *et al.*, 2020) 7 – 27% of cases in Germany (Koch & Stark, 2006; Preußel *et al.*, 2015) 8% of cases in Denmark (Gerner-Smidt *et al.*, 2005) 9% of CNS and 9% of bacteraemia cases in England and Wales (Gillespie *et al.*, 2009) 9% of cases in Australia (Dalton *et al.*, 2011) 10% of cases in the Netherlands (Doorduyn, de Jager, *et al.*, 2006) 10 – 14% of cases in US (Bennion *et al.*, 2008; Silk *et al.*, 2012; Tran *et al.*, 2023) 22% of cases in France (Charlier *et al.*, 2017) 29% of cases in Finland (Suominen *et al.*, 2023)
Salmonella	Prevalence data not included in reviewed studies
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among people with diabetes

Of the 166 listeriosis cases in Scotland between 2012 – 2022, 10% were among people with diabetes, it was further reported that 94% of which were aged >65 years (Public Health Scotland, no date).

Reviewed studies indicated that of listeriosis cases, between 7% (in Italy (Gori *et al.*, 2020) and Germany (Koch & Stark, 2006)) and up to 29% in Finland (Suominen *et al.*, 2023), were among people living with diabetes (Table 11). However, it must be noted that studies did not differentiate between type 1 and type 2 diabetes.

One study reported that incidence was at a low rate of <0.5 cases per 100,000 people, for individuals with type 2 diabetes (Goulet *et al.*, 2012). A comparable incidence rate for people with type 1 diabetes was not available. As part of the review, it was found that some studies grouped diabetes with other conditions, for example, it was reported that 33% of listeriosis cases in Spain had diabetes mellitus, high blood pressure, or hyperlipidaemia listed as underlying conditions (Vallejo *et al.*, 2022).

Fatal outcomes occurred more frequently in hospitalised individuals with listeriosis and co-diagnosis of diabetes mellitus (adjusted RR: 1.33; 95% CI: 1.10-1.60) than those without diabetes (Herrador *et al.*, 2019), 13% of listeriosis-related mortality had diabetes mellitus and/or high blood pressure (Vallejo *et al.*, 2022).

Salmonella among people with diabetes

As indicated in Table 2, 5% of confirmed Salmonella cases between 2013-2017 in Scotland were reported to have diabetes listed as an underlying condition (Food Standards Scotland, 2020a).

Only two of the reviewed studies referred to an association between diabetes and Salmonella. Data detailing the proportion of reported salmonellosis cases with diabetes were not available. However, Turgeon *et al.* (2017) reported that 19% of Salmonella hospitalisations among older adults in Canada had both cardiovascular disease and diabetes as underlying conditions and Cummings *et al.* (2010) reported that 8% of Salmonella-related deaths in US had diabetes.

E. coli, Campylobacter and Norovirus among people with diabetes

Although 7% of Campylobacter cases in Scotland were among people with diabetes, comparable data from the reviewed studies (*n*=138) were not available. Data detailing prevalence of diabetes among cases of *E. coli* and norovirus were not available from Scotland or in the reviewed studies (*n*=138).

4.1.9. People with inflammatory bowel disease as a clinically vulnerable group

Crohn's disease and ulcerative colitis (UC) are two types of Inflammatory Bowel Disease (IBD) characterised by chronic inflammation in the gastrointestinal (GI) tract (de Mattos *et al.*, 2015). The disease is progressive over time, and inflammation causes damage to the GI lining (Marks *et al.*, 2010). Crohn's disease affects the ileum, close to the colon, and creates patches of damaged epithelium called cobblestones. Inflammation in Crohn's disease penetrates multiple layers of the intestine. In UC, the damage occurs starting in the rectum and spreading further into the colon. Inflammation is present in the innermost lining of the intestine (CDC, 2022; Marks *et al.*, 2010). Although the causes of IBD are not well understood, it is accepted that the inflammation of the GI tract is caused by the immune system malfunctioning and incorrectly responding to environmental triggers, such as a virus or bacteria (Cobrin & Abreu, 2005). Gut T-cells in Crohn's disease react toward their own autologous flora (Neurath, 2004).

IBD results in imbalances in the gut microbiota, potentially favouring the growth of harmful bacteria. This dysbiosis can make it easier for foodborne pathogens to establish themselves in the gut. The malfunctioning of the immune system, the damage of the epithelial lining, and microbiome dysbiosis in individuals with Crohn's disease and UC create conditions for opportunistic and foodborne pathogens to invade (Qiu *et al.*, 2022).

The prevalence of either regulatory (eubiosis) or inflammatory (dysbiosis) species within the gut microbial community determines the respective predominant immune response in Crohn's disease (Santana *et al.*, 2022). Gut dysbiosis is linked to lower mucus thickness, decreased antimicrobial defence and butyrate and propionate production. Secretion of gut peptides by intestinal endocrine cells is decreased, and the lack of activation of PPAR-γ leads to higher oxygen availability for the microbiota

at the proximity of the mucosa and increases the proliferation of Enterobacteriaceae (Cani, 2018). The decrease in propionate also contributes to the lower level of mucosal T-cells. Additionally, microbiome dysbiosis induces a leakage of pathogen associated molecular patterns such as the LPS that trigger low-grade inflammation and can be detected in blood (Cani, 2018).

In IBD, medical therapies that diminish the mucosal inflammatory response represent the foundation of treatment in IBD (Axelrad *et al.*, 2016). The medications include steroids, monoclonal antibodies to IL-12/23 or integrin α4β7, immunomodulators, or combination therapies (Cushing & Higgins, 2021). The medications predispose individuals to infections, cancers associated with immune modulators and biologics, and toxicity to the liver and bone marrow (Cushing & Higgins, 2021).

People with inflammatory bowel disease in Scotland

It is reported that over half a million people in the UK are living with IBD, although this equates to 0.81% of the population, one in every 123 people are living with Crohn's or colitis (Crohn's & Colitis UK, 2022). In Scotland, there are over 50,000 people living with Crohn's or colitis, which is one in every 103 people, which is the highest proportion of the population anywhere in the UK (Crohn's & Colitis UK, no date). It is also reported that occurrence of Crohn's or colitis increases with age, with 1 in every 67 for people aged over 70. The UK is second only to the US in terms of percentage of the population living with IBD, and this is anticipated to increase (Crohn's & Colitis UK, 2022).

Prevalence of foodborne illness and inflammatory bowel disease

The review of 138 studies established that four studies included information regarding foodborne illness among people living with IBD, of these, three referred to listeriosis and one included campylobacteriosis (Table 12).

Table 12. Prevalence of foodborne pathogens associated with people with IBD in reviewed studies (*n*=4) (*L. monocytogenes* *n*=3; Salmonella *n*=0; Campylobacter *n*=1; *E. coli* *n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were among people with IBD)
L. monocytogenes	1% of cases in France had Crohn's disease (Goulet *et al.*, 2012) 3% of cases in Australia had IBD/irritable bowel disease (IBS)/Crohn's disease (Dalton *et al.*, 2011)
Salmonella	No data available
E. coli	No data available
Campylobacter	5% of *Campylobacter jejuni* cases in the Netherlands had IBD, IBS or coeliac disease (Doorduyn *et al.*, 2010)
Norovirus	No data available

L. monocytogenes among people with inflammatory bowel disease

No data were available regarding prevalence of listeriosis among individuals with IBD as an underlying condition in Scotland. Two of the reviewed studies indicated that between 1 – 3% of listeriosis cases had IBD, IBS or Crohn's disease as an underlying condition (Dalton *et al.*, 2011; Goulet *et al.*, 2012) (Table 12). A Canadian study reported that preexisting GI problems were much more common in individuals with listeriosis (66%) than in individuals with campylobacteriosis or salmonellosis (p= 0.001). Of 15 case patients with listeriosis, 33% had IBD (Schlech *et al.*, 2005).

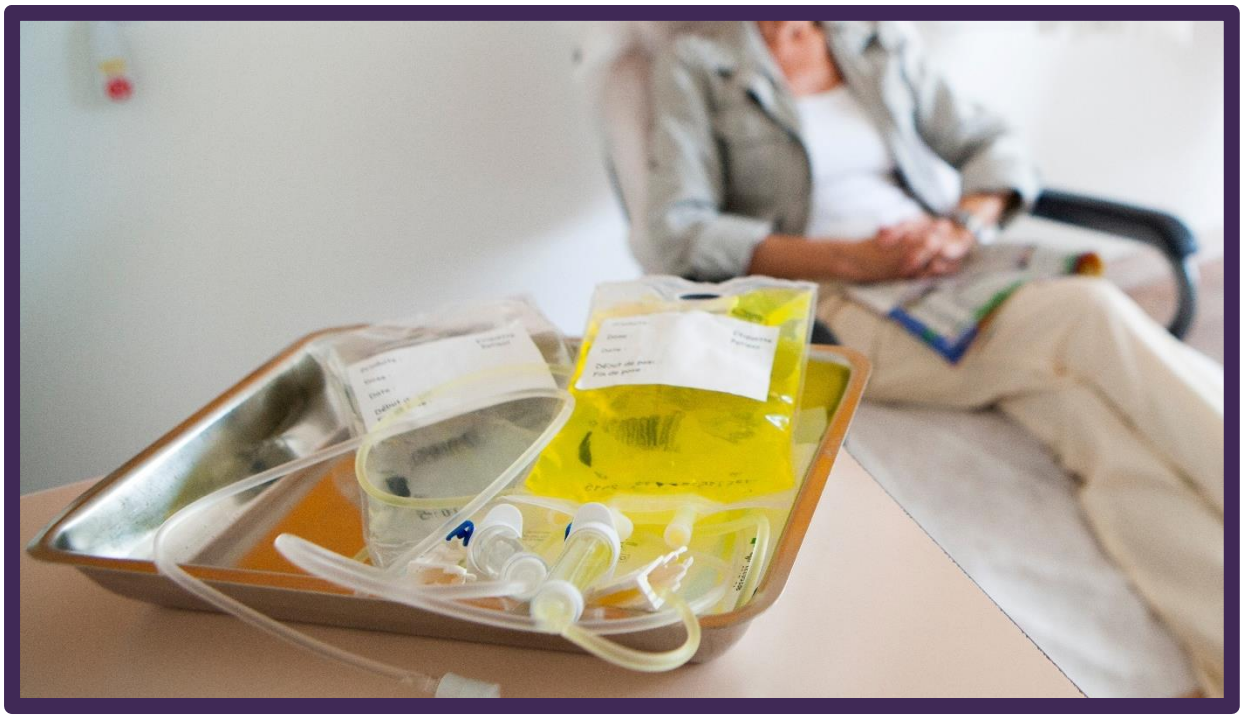
Campylobacter among people with inflammatory bowel disease

No data were available regarding campylobacteriosis among individuals with IBD as an underlying condition in Scotland. Data from the Netherlands reported that 5% of *C. jejuni* infections were among individuals with IBD, IBS or coeliac disease (Doorduyn *et al.*, 2010)

Salmonella, *E. coli,* and norovirus among people with inflammatory bowel disease

Data regarding prevalence of foodborne illness among people with IBD were not available in data obtained from Scotland or from the reviewed studies for cases of Salmonella, *E. coli,* and norovirus.

4.1.10. People with cancer as a clinically vulnerable group



Cancer is a set of diseases that are characterised by growth of damaged cells that multiply instead of undergoing the cell death process (National Cancer Institute, 2021). The cell growth deviates from the normal cell life cycle, and the host immune system cannot control it. These cells form tumours that can be benign or malignant and can spread to other tissues and systems in the body. The tumours can form anywhere in the body, making the disease organ-, or system-specific (Cooper, 2000). Approximately 40% of people will be diagnosed with cancer at some point during their lifetimes (Siegel *et al.*, 2017).

People living with cancer are at an increased risk of infection, including foodborne illness. In cancer, both the disease biology and the treatments against cancer cause changes in the immune system. Regulatory T-cells appear to play an important role in tolerance to tumour antigens, resistance of tumours to immune-mediated elimination, as well as general downregulation of immune responses to pathogens (Pardoll, 2015). Cell-mediated immune defects can be due to the basic disease like Hodgkin's disease, T-cell lymphomas, leukaemia, B-cell defects in multiple myeloma and chronic lymphocytic leukaemia, or bone marrow transplants (Griggio *et al.*, 2020; Ioannou *et al.*, 2021).

Chemotherapy in cancer has potent cytotoxic effects on both the innate and adaptive immune system. These impacts present an additional layer of damage to the host immune system which may have already been compromised by factors related to the biology of the disease. The therapy affects T-cells, monocytes/ macrophages, neutrophils, and the integrity of the gastrointestinal mucosa (Nesher & Rolston, 2014). Individuals with cancer are therefore highly susceptible to almost any type of infection, especially bacterial and fungal. Furthermore, and importantly, all types of infections are associated with higher rates of morbidity and mortality in individuals undergoing cancer chemotherapy. Chemotherapy, targeted cell therapy, and some

radiations temporarily reduce the number of neutrophils in the blood and lead to higher infection risks during and after the therapy (Vento & Cainelli, 2003). Lower-than-normal neutrophil levels, or neutropenia, predispose individuals receiving treatment to infections. Neutrophil counts lower than 0·5109/L for longer than 10 days are viewed as a general threshold for more frequent and severe infections (Vento & Cainelli, 2003).

Cancer immunotherapy is designed to alter the host immune response and increase efficacy of immune-mediated elimination of cancer cells. However, immunotherapy can lead to several immune-related adverse effects that alter the immune response to pathogens (Tanoue *et al.*, 2019). Several types of therapies can be used including monoclonal antibodies, T-cell transfer therapy, immune system modulators, and immune checkpoint inhibitors (National Cancer Institute, 2019). Checkpoint inhibitors block receptors expressed on effector T-cells and bind to antigen-presenting cells (APCs). These checkpoint receptors (PD-1, CTLA-4) act as breaks in the immune response to balance and prevent an over-exuberant response, such as chronic inflammation (Morelli *et al.*, 2022; Tanoue *et al.*, 2019). The increased susceptibility to foodborne illness and severe illness can be temporary or long-term. Other co-morbidities, chronic or acute conditions caused by cancer, and treatments contribute to the decreased ability of the immune system to mount the immune defence. For instance, poor nutrition, GI problems, and polypharmacy (the simultaneous use of multiple medicines by an individual for their conditions) not related to cancer treatment can lead to further vulnerability (Goede, 2023).

People with cancer in Scotland

Nearly 1 in 2 people born in the UK in 1961 will be diagnosed with some form of cancer during their lifetime (Cancer Research UK, 2024b). There were 35,379 new cancers registered in Scotland in 2021, with a reported rate of new cancers of 644 per 100,000 population (Public Health Scotland & National Statistics, 2023b). The overall risk of developing cancer in 2021 was 30% higher in the most deprived areas compared with the least deprived areas of Scotland (Cancer Research UK, 2022). Incidence rates for cancer in the UK are highest in people aged 85 to 89, and 36% of all cancer cases in the UK are diagnosed in people aged ≥75 years (Cancer Research UK, 2024a). In Scotland during 2021, 77% of cancer diagnoses were in people aged ≥60 years (Public Health Scotland & National Statistics, 2023b).

Prevalence of foodborne illness among people with cancer

Twenty nine of the 138 reviewed studies provided information regarding the occurrence of foodborne illness among people with cancer. Of these, 27 included *L. monocytogenes* and two included Salmonella. Some of these studies provided data detailing prevalence among people with cancer receiving specific treatment (e.g. chemotherapy or radiation therapy), referred to specific types of cancer (e.g. solid cancer or haematological malignancy) or listed cancer as an underlying condition without specifying the cancer type of treatment (Table 13).

Table 13. Prevalence of foodborne pathogens among people with cancer in reviewed studies (*n*=29) (*L. monocytogenes* *n*=27; Salmonella *n*=2; Campylobacter *n*=0; *E. coli* *n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were reported to be cancer associated cases)
L. monocytogenes	**Cancer associated cases:** 8% of cases in the Netherlands (Doorduyn, de Jager, *et al.*, 2006) 13% of cases in Germany (Preußel *et al.*, 2015) 18 – 23% of cases in US (Silk *et al.*, 2012; Silk *et al.*, 2013; Tran *et al.*, 2023) 21% of cases in Finland listed cancer and leukaemia as underlying conditions (Suominen *et al.*, 2023) 25% of cases in Portugal (Magalhaes *et al.*, 2014) 23% of cases in Spain (Herrador *et al.*, 2019) 30 – 32% of cases in Italy (Gori *et al.*, 2020) 18 – 31% of cases in Australia (Dalton *et al.*, 2011; Leung *et al.*, 2018) **Cancer treatment associated cases:** 5% of cases in Germany were radiation therapy (Preußel *et al.*, 2015) 7% of cases in England and Wales were prescribed cytotoxic drugs for cancer (Mook *et al.*, 2013) 13% of cases in Germany were receiving chemotherapy (Preußel *et al.*, 2015) 14% of cases in Australia were receiving chemotherapy and/or radiotherapy (Leung *et al.*, 2018) 15% of CNS and 15% bacteraemia cases in England and Wales were prescribed cytotoxic drugs for cancer (Gillespie *et al.*, 2009)
Salmonella	Prevalence data not included in reviewed studies
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among people with cancer

Listeria surveillance data from Scotland indicated that 19% of the 166 cases of listeriosis (2012 – 2022) had malignancy listed as an underlying condition (Public Health Scotland, no date).

Twenty-seven studies provided insight to the prevalence of listeriosis among people with cancer, as indicated in Table 13, studies indicated that between 8% of cases in the Netherlands (Doorduyn, de Jager, *et al.*, 2006) and 32% of cases in Italy (Gori *et al.*, 2020) were among people with cancer.

Of the studies that included details regarding treatment among people with cancer, only one study listed radiation therapy, it was established that 5% of cases in

Germany were people receiving radiation therapy for cancer (Preußel *et al.*, 2015). Leung *et al.* (2018) reported that 14% of all notifications in Australia were people receiving cancer drugs (radiotherapy and/or chemotherapy). Data from England and Wales indicated that 7% of listeriosis cases (Mook *et al.*, 2013), 15% of central nervous system infections and 15% of bacteraemia cases were prescribed cytotoxic drugs for cancer (Gillespie *et al.*, 2009).

Some studies suggested that prevalence was higher among people with blood cancers than solid tumours, whereas others reported the opposite. For example, Guerrero *et al.* (2012) reported that 25% of listeriosis cases were among people with blood cancer and 13% had solid tumours, whereas Preußel *et al.* (2015) reported that 8% of cases had blood cancer and 15% had solid tumour cancer.

In terms of case fatalities, 11% of listeriosis fatalities in the US listed cancer as an underlying cause (Bennion, 2008) whilst 45% of listeriosis fatalities in the UK had solid organ malignancies (Scobie 2019). The incidence rate of listeriosis among people with cancer was reported to be 3.75 per 100,000 people in France (Goulet *et al.*, 2012).

Salmonella among people with cancer

Occurrence of Salmonella among people living with cancer or receiving treatment for cancer were not available in Scotland. Similarly, prevalence of Salmonella among people with cancer was seldom referred to in reviewed studies (Table 13).

A Canadian study reported that among people aged ≥60 years, hospitalised with non-typhoidal Salmonella, 60% were also diagnosed with at least one of the four chronic diseases including cancer (Turgeon *et al.*, 2017). A US study on salmonellosis hospitalisations between 2000 and 2011 reported that Lymphoma was associated with the greatest salmonellosis disease severity that can impair the immune system with an adjusted OR of 4.34 (95% CI = 1.39, 13.54) (Cummings *et al.*, 2016).

E. coli, Campylobacter, and norovirus among people with cancer

Data detailing prevalence of *E. coli,* Campylobacter and norovirus were not available from Scotland or in the reviewed studies (*n*=138).

4.1.11. People with HIV/AIDS as a clinically vulnerable group

HIV/AIDS infection causes profound defects in the immune system that lead to severe susceptibility to infection in people living with AIDS (Perelson, 1989). HIV infection leads to the depletion of CD4 T-cells, which leaves individuals mortally susceptible to opportunistic infections (Mishra *et al.*, 2009). Structural and immunological changes occur at the mucosal surfaces from the very onset of HIV infection (Xu *et al.*, 2013). The GI tract is a major site of HIV replication, resulting in major loss of CD4 T-cells during acute infection, and the loss of mucosal immunity over time. Additionally, the GI mucosa is infiltrated with cytotoxic CD8 T-cells leading to disruption of tight epithelial junctions making HIV a disease of the GI tract (George *et al.*, 2005).

People with HIV/AIDS in Scotland

In 2022, an estimated 6,600 people were living with HIV in Scotland, of whom 6,150 (93%) had been diagnosed. Of those engaged with HIV services, 98% were receiving antiretroviral therapy and, of those, 93% were recorded as having an undetectable viral load (Public Health Scotland, 2023).

Prevalence of foodborne illness among people with HIV/AIDS

A total of 10 studies included information regarding the proportion of foodborne cases that were among people with HIV/AIDS, eight of these studies included *L. monocytogenes,* whilst two included Salmonella. No data were available from Scotland in relation to foodborne illness prevalence among people living with HIV/AIDS.

Table 14. Prevalence of foodborne pathogens among people with HIV/AIDS in studies (*n*=10) (*L. monocytogenes n*=8; Salmonella *n*=2; Campylobacter *n*=0; *E. coli n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were among people with HIV/AIDS)
L. monocytogenes	1% of cases in France (Goulet *et al.*, 2012) 2% of cases in Norway (Antal *et al.*, 2007) 2% of cases in Australia (Dalton *et al.*, 2011) 3% of cases in Spain (Herrador *et al.*, 2019) 6% of cases in US (Silk *et al.*, 2013)
Salmonella	Prevalence data not included in reviewed studies
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among people with HIV/AIDS

Data regarding prevalence of HIV/AIDS among cases of listeriosis were not available from Scotland. Of the 138 reviewed studies, as indicated in Table 14, eight included data regarding prevalence of listeriosis among people living with HIV/AIDS, the studies suggested that between 1% (Goulet *et al.*, 2012) and 6% (Silk *et al.*, 2013) of listeriosis cases had HIV/AIDS listed as an underlying condition. Incidence data were not available.

Bennion *et al.* (2008) reported that listeriosis was positively associated with HIV infection (OR, 4.19; 95% confidence interval, 3.06–5.73), with 4.2% of listeriosis-associated deaths having HIV as a comorbidity, whilst 1.1% of non–listeriosis-associated deaths had HIV as a comorbidity. It was also reported that the frequency of HIV listed as a comorbidity among listeriosis-related deaths reduced from 5% between 1990 and 1995, to 3% by 2005 (Bennion *et al.*, 2008).

Salmonella among people with HIV/AIDS

Data regarding prevalence of HIV/AIDS among cases of salmonellosis were not available from Scotland. Two of the reviewed studies included information regarding the association between Salmonella and HIV/AIDS. None of the studies provided data detailing the proportion of Salmonella cases that were among people with HIV/AIDS. However, the reviewed studies indicated that 12% of Salmonella hospitalisations in Spain over a ten-year period had HIV as an underlying condition (Prieto *et al.*, 2009), and on the basis of matched case–control analysis, in the US, 10% of Salmonella-related deaths were associated with HIV compared to 2% of non-Salmonella-related deaths (Matched OR: 7.44 (95% CI 5.04–10.97) (Cummings *et al.*, 2010).

E. coli, Campylobacter, and norovirus among people with HIV/AIDS

As with some of the other underlying conditions in this report, prevalence of HIV/AIDS among cases of *E. coli,* Campylobacter, and norovirus were not available in the reviewed studies (*n*=138) or in data obtained from Scotland.

4.1.12. People with alcohol use disorders as a clinically vulnerable group

Terms such as 'alcoholic' and 'alcoholism', are not clinical terms and are associated with stigma and so should not be used. Terms such as 'person with alcohol use disorder ' should be used instead (Poorman et al., 2024). The National Institute on Alcohol Abuse and Alcoholism describe alcohol use disorder as a spectrum ranging from mild to severe (National Institute on Alcohol Abuse and Alcoholism, 2020) , with the amount alcohol only being one criterion for determining the severity of the disorder (Babor et al., 2001)

Alcohol use disorder and excessive alcohol consumption cause a significant public health problem globally, with 2.5 million deaths related to alcohol abuse and comorbidities (World Health Organization, 2012). Alcohol remains one of the leading causes of disability and premature death in many regions (Murray & Lopez, 1997). Short and long-term exposure to alcohol can cause alcohol dependence and several liver diseases like cirrhosis, cancers, and organ damage, including the immune system. Alcohol use disorder affects both the innate and adaptive immune system (Sarkar *et al.*, 2015). Even moderate alcohol consumption impacts the immune response, affecting the frequency, survival, and function of immune cells (Szabo & Saha, 2015). Production of smaller amounts of immune cells with impaired efficiency makes alcoholics immunosuppressed at the sub-clinical level, and more prone to contracting foodborne and other infections.

The GI tract is the first point of contact for alcohol. Frequent consumption of alcohol affects the structure and integrity of the mucosa and further impairs T-cell mediated responses (Hammer *et al.*, 2015).

Damage to epithelial cells, the mucosal immune system, T-cells, and neutrophils in the GI system leads to disruption of the gut barrier function and facilitates leakage of pathogens into the circulation. The gut microbiome dysbiosis indirectly disrupts

maturation and function of the immune system (Hammer *et al.*, 2015). Gut dysbiosis is linked to lower mucus thickness, decreased antimicrobial defence, butyrate and propionate production and a cascade of changes leading to an increased risk of Enterobacteriaceae proliferation and severe GI infections (see IBD section for details) (Cani, 2018).

People with alcohol use disorders in Scotland

The Scottish Health Survey reported that the prevalence of hazardous or harmful levels of weekly alcohol consumption have declined steadily since 2003, from 34% to 23% in 2021. Prevalence of hazardous or harmful weekly alcohol consumption was twice as high for men (31%) as for women (16%), were highest among those aged between 45 and 74, and were more common in the least deprived areas (Scottish Government, 2022). Tools used to identify alcohol use disorders often do not specify the exact quantity of alcohol considered hazardous or harmful and take additional factors into account during the evaluation (Babor et al., 2001).

The volume of pure alcohol sold per adult in Scotland in 2022 was 4% higher than in England and Wales (Ponce-Hardy & Giles, 2023). In 2022, there were 1,276 alcohol-specific deaths and the rate of mortality was 22.9 deaths per 100,000 people. Alcohol-specific deaths were 4.3 times as high in the most deprived areas of Scotland compared to the least deprived areas. This compares to a ratio of 1.8 times for all causes of death (National Records of Scotland, 2023a).

Prevalence of foodborne illness among people with alcohol use disorders

A total of 11 studies included information regarding the percentage of foodborne illness cases that were associated with alcohol use disorders, 10 of which included listeriosis, one included salmonellosis.

Table 15. Prevalence of foodborne pathogens associated with alcohol-related disorders in reviewed studies (*n*=11) (*L. monocytogenes* *n*=10; Salmonella *n*=1; Campylobacter *n*=0; *E. coli* *n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were related to alcohol use disorders)
L. monocytogenes	4% of cases in Finland (Suominen *et al.*, 2023) 6% of cases in US (Silk *et al.*, 2012; Silk *et al.*, 2013) 6% of cases in Norway (Antal *et al.*, 2007) 11% of cases in Denmark (Gerner-Smidt *et al.*, 2005)
Salmonella	Prevalence data not included in reviewed studies.
E. coli	No data available
Campylobacter	No data available
Norovirus	No data available

L. monocytogenes among people with alcohol use disorders

As indicated in Table 2, the data obtained from Scotland reported that 4% of the confirmed listeriosis cases between 2012 and 2022 had alcohol related conditions listed as an underlying condition (Public Health Scotland, no date). Likewise, as indicated in Table 15, the data extracted from reviewed studies suggested that between 4 – 11% of listeriosis cases had alcohol-related disorders, alcohol overuse, or alcoholism listed as an underlying condition (Antal *et al.*, 2007; Gerner-Smidt *et al.*, 2005; Silk *et al.*, 2012; Silk *et al.*, 2013; Suominen *et al.*, 2023). Data from England and Wales indicated that 4% of listeriosis cases among those aged >60 years had alcohol-related disorders as an underlying condition (Gillespie *et al.*, 2006) Disease presentation data indicated that 4% of bacteraemia and 10% of central nervous system infection cases were alcohol-related (Gillespie *et al.*, 2009).

A US study on the risk factors for mortality among non-perinatal listeriosis patients reported that 28% of cases were among individuals with alcoholism (adjusted OR, 4.63; 95% CI, 1.36-15.8) (Guevara *et al.*, 2009), whilst a UK study on the mortality risk factors for listeriosis reported that 22% of listeriosis cases with alcohol listed as a comorbidity resulted in mortality (Scobie *et al.*, 2019). Incidence rates for listeriosis among individuals with alcohol-related underlying conditions were not available.

Salmonella among people with alcohol use disorders

A breakdown of salmonellosis incidence data according to alcohol-related issues were not available from Scotland. The one study to include information regarding alcohol-related conditions reported that 3% of salmonellosis-related mortality in the US had alcohol and drug abuse listed as underlying conditions (Cummings *et al.*, 2010).

E. coli, Campylobacter, and norovirus among people with alcohol use disorders

Data regarding prevalence of alcohol-related conditions among cases of *E. coli,* Campylobacter, and norovirus were not available in data obtained from Scotland or the reviewed studies.

4.1.13. Transplant recipients as a clinically vulnerable group

Individuals who have received transplants receive immunosuppressive agents to maintain graft function. These agents make organ transplant recipients prone to infections (Fishman, 2011). A variety of immunosuppressants are used, depending on organ and recipient characteristics. Common immunosuppressants include antibodies to cell surface antigens on lymphocytes, anti-interleukin 2 (IL-2) receptor antibodies, calcineurin inhibitors, lymphocyte proliferation inhibitors, glucocorticoids, and others (Tönshoff, 2020).

Immunosuppression impacts both the innate and adaptive immunity. T-cells and B-cells are depleted making the individuals more susceptible to viral and bacterial pathogens. The use of corticosteroids is also linked to a risk of fungal infections among organ transplant recipients (Seok *et al.*, 2020). The level of immunosuppression among organ recipients depends on the type, duration, and intensity of immunosuppressive therapy (Pilch *et al.*, 2021). Prior therapies (e.g., chemotherapy, antibiotics, etc.), and the level of neutropenia or lymphopenia impact the level of immune dysfunctions.

Other, non-transplant related underlying conditions such as autoimmune disease, metabolic conditions, diabetes, malnutrition, alcohol use disorder, chronic viral infections, and age add an additional layer to the vulnerability of these individuals.

Transplant recipients in Scotland

During 2022/2023, 4,533 people received organ transplantation in the UK (Statistics and Clinical Research & NHS Blood and Transplant, 2023), 391 of which were in Scotland. The majority (60%) received kidney transplants (NHS Blood and Transplant, 2023).

Prevalence of foodborne illness among transplant recipients

No data were available regarding prevalence of foodborne illness among transplant recipients (Table 2). From the reviewed studies, nine included data detailing prevalence of foodborne illness associated with transplantation, as indicated in Table 16, seven of these related to listeriosis, one referred to Salmonella and one referred to Campylobacter.

Table 16. Prevalence of foodborne pathogens associated with transplantation in reviewed studies (*n*=9) (*L. monocytogenes* *n*=7; Salmonella *n*=1; Campylobacter *n*=1; *E. coli* *n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were among people that had received a transplantation)
L. monocytogenes	1% of cases in Finland had received a tissue transplant (Suominen *et al.*, 2023) 3% of cases in Australia had received a transplant (Dalton *et al.*, 2011) 4% of cases in Germany had received a solid organ transplantation (Preußel *et al.*, 2015)
Salmonella	Prevalence data not included in reviewed studies
E. coli	No data captured
Campylobacter	Prevalence data not included in reviewed studies
Norovirus	No data captured

L. monocytogenes among transplant recipients

No data were available from Scotland detailing the proportion of listeriosis cases that were among people that had received transplants. The reviewed studies indicated that between 1 – 4% of listeriosis cases were among people that had undergone transplantation. It was determined that of listeriosis-associated deaths in the US, 0.5% were reported to be among organ transplantation recipients (OR: 7.25, 95% CI, 3.2-16.19) (Bennion *et al.*, 2008) (Table 16). It was suggested that in comparison to other underlying conditions, the case fatality rate of listeriosis in France was lowest for organ recipients (6%) (Goulet *et al.*, 2012).

Salmonella among transplant recipients

Information regarding the prevalence of transplant recipients among cases of Salmonella were not available from Scotland or in reviewed studies. However, a study regarding confirmed foodborne infections among solid organ transplant recipients reported that in a cohort of 4,405 recipients, 151 episodes of foodborne infections were reported, 10% of which were non-typhoidal Salmonella and the standardised incidence rate was 4.6 (95% confidence interval, 2.6-7.5) (van den Bogaart *et al.*, 2022).

Campylobacter among transplant recipients

Although data detailing the proportion of transplant recipients among Campylobacter cases in reviewed studies or in Scotland were not available, as with Salmonella, van den Bogaart *et al.* (2022) reported that of the 151 cases of foodborne illness among 4,405 transplant recipients, 88% of these infections were *Campylobacter* spp., where the standardised incidence rate was 7.4 (95% CI, 6.2-8.7).

E. coli and norovirus among transplant recipients

Data regarding prevalence of *E. coli* or norovirus among people that had received a transplantation were not available in data obtained from Scotland or the reviewed studies.

4.1.14. Medications that create clinically vulnerable groups

Data detailing prevalence of foodborne illness associated with specific medication for exact underlying conditions e.g. cancer treatment, rheumatoid arthritis, diabetes, and proton pump inhibitors have been discussed, however some data suggest that other medications such as antibiotics and corticosteroids are also associated with prevalence of foodborne illness.

Antibiotics disrupt the gut microbiome and cause dysbiosis that leads to increased susceptibility to infections with opportunistic and antimicrobial-resistant foodborne pathogens. This gut microbiota dysbiosis (Neuman *et al.*, 2018) results in a reduction in the diversity and abundance of gut microorganisms, changes in gene expression and protein activity, and compromises defences against invading harmful bacteria (Kesavelu & Jog, 2023). Antibiotic use also contributes to the emergence of antibiotic-resistant pathogens (Francino, 2015).

Corticosteroids are extremely effective in the treatment of acute inflammation and chronic inflammatory diseases. Despite this, there are multiple serious adverse effects associated with corticosteroids including bone fractures, osteoporosis, hyperglycaemia, and susceptibility to infections (Manson *et al.*, 2009). Corticosteroids suppress the immune system (Heming *et al.*, 2018) by blocking some pro-inflammatory proteins like bioactive amines, lipid mediators, and cytokines (TNF-α and IL-1) which leads to decreased capillary permeability (humoral response) and reduced leukocyte migration into inflamed tissues (Coutinho & Chapman, 2011). Because there is no vasodilation, the redness and pain which are the symptoms of infection, are masked (Heming *et al.*, 2018). The use of glucocorticoids makes the individual susceptible to foodborne bacteria, viruses, and fungi (Reichardt *et al.*, 2021).

Antibiotic and corticosteroid use in Scotland

It was reported that 23% of the Scottish population received at least one course of antibiotics during 2021. The total use of antibiotics across all settings was 19.0 defined daily doses per 1,000 population per day. It is reported that 84% of antibiotic use occurred in the community setting rather than the hospital setting (ARHAI Scotland, 2022).

Data regarding corticosteroid use in Scotland were not available. Historic UK data suggested that oral corticosteroids were being used by 0.9% of the total adult population and that the highest use was among people between 70 and 79 years of age (2.5%) (van Staa *et al.*, 2000).

Prevalence of foodborne illness associated with medications

In the reviewed studies, it was discovered that medications that affect the immune response including cytotoxic drugs, corticosteroids and antibiotics are often grouped together, making individual comparisons challenging. Some simply stated that individuals had received immunosuppressive therapies and further information whether these were prescribed for cancer treatment or other underlying conditions were often not included. As indicated in Table 17, a total of 21 studies provided information regarding prevalence of foodborne illness among people taking specific medications, 17 of these referred to listeriosis, while three related to campylobacteriosis and one referred to salmonellosis.

Table 17. Prevalence of foodborne pathogens associated with medication in reviewed studies (*n*=21) (*L. monocytogenes n*=17; Salmonella *n*=1; Campylobacter *n*=3; *E. coli n*=0; norovirus *n*=0).

Pathogen	Prevalence data (percentage of cases that were among people that had received various medications)
L. monocytogenes	**Steroid use:** 11% of cases in Spain associated with high-dose corticosteroid therapy (Guerrero *et al.*, 2012) 32% of cases in Australia had systemic steroids 4 weeks prior to notification (Leung *et al.*, 2018) 43% of cases in France had received corticosteroids or other immunosuppressive therapies in the 5 years prior to infection (Charlier *et al.*, 2017) **Immunosuppressive treatments:** 9% of cases in Germany received immune suppressive treatments (Koch & Stark, 2006) 18 – 25% of cases in US had immunosuppressive therapy (including steroid treatment, chemotherapy, and radiation) (Silk *et al.*, 2012; Silk *et al.*, 2013) 29% of cases in Denmark had received immunosuppressive treatment (Gerner-Smidt *et al.*, 2005) 29% of cases in the Netherlands had received immunosuppressive therapy (Doorduyn, de Jager, *et al.*, 2006) 40% of cases in Finland had immunosuppressive medication 3 months prior to infection (Suominen *et al.*, 2023) 41% of cases in France had immunosuppressive treatment (Goulet *et al.*, 2012) 44% of cases in Germany received immunosuppressive therapy within 3 months prior to illness onset (Preußel *et al.*, 2015) 50% of cases in Australia had antidiarrheals, antacids, and antibiotics in 4 weeks prior to notification (Leung *et al.*, 2018)
Salmonella	17% of *Salmonella typhimurium* DT104 and 7% of non-DT104 infection cases took antibiotics in the 4 weeks prior to illness (Dore *et al.*, 2004)
E. coli	No data captured
Campylobacter	Prevalence data not included in reviewed studies
Norovirus	No data captured

L. monocytogenes associated with medications

No data were available from Scotland detailing the proportion of listeriosis cases that were among people that had received antibiotics or corticosteroids.

Of the reviewed studies, 17 presented data regarding listeriosis associated with medications (Table 17). In a review of medications most commonly taken by non-pregnancy-related listeriosis patients in the UK prior to illness, Mook *et al.* (2013)

reported that the rates for cytotoxic drugs, drugs affecting the immune response and corticosteroids were significantly higher than for other medications. Treatment with antibiotics was reported to be significantly more common among individuals with listeriosis in Canada than in individuals with campylobacteriosis or salmonellosis (Schlech *et al.*, 2005). It was reported that 23% of bacteraemia and 27% of central nervous system infections in England and Wales had received steroids, and 16 – 17% had received immunosuppressive treatment (Gillespie *et al.*, 2009).

Medication known to suppress the immune response including antidiarrheals, antacids, and antibiotics were reported to be taken 4 weeks prior to 50% of listeriosis notifications and systemic steroids were reported to be taken during the 4 weeks prior to 32% listeriosis notifications in Australia (Leung *et al.*, 2018).

Salmonella associated with medications

As indicated in Table 2, 10.5% of Salmonella cases in Scotland were prescribed an antibiotic in the 30 days preceding infection. One study from the 138 that were reviewed included data regarding prevalence of Salmonella associated with medication such as antibiotics. As indicated in Table 17, Dore *et al.* (2004) reported that 7 – 14% of Salmonella cases in Canada were associated with antibiotic use, indeed taking antibiotics in the 4 weeks before illness was a risk factor for *Salmonella typhimurium* DT104 in Canada.

Campylobacter associated with medications

It was established that 6% of Campylobacter cases in Scotland (Table 2) were prescribed an antibiotic in the 30 days preceding infection. Three of the reviewed studies reported on Campylobacteriosis associated with medication usage. Cribb *et al.* (2022) and Doorduyn *et al.* (2010) reported that recent antibiotic use was associated with reduced odds of campylobacteriosis while Fajó-Pascual *et al.* (2009) reported that previous antibiotic intake was associated with illness.

E. coli and norovirus associated with medications

Data regarding prevalence of *E. coli* and norovirus among people that had received medication such as antibiotics and steroids were not available in data obtained from Scotland or the reviewed studies.

4.1.15. Underlying conditions that create clinically vulnerable groups of the population

L. monocytogenes and underlying conditions

As indicated in Table 2, *L. monocytogenes* was most frequently included in reviewed studies, of the 138 studies, 58 included *L. monocytogenes.* The reviewed data suggests that underlying conditions are important in relation to the occurrence of listeriosis. For example, it was reported that the increased incidence of listeriosis among individuals aged ≥60 years in England and Wales between 2001 and 2007 occurred in those with underlying conditions such as cancer or other conditions whose treatment included acid-suppressing medication. Only 10% of bacteraemia and 26% of central nervous system cases did not have an underlying condition listed (Gillespie *et al.*, 2009) and only 11% of individuals had no underlying condition (Gillespie *et al.*, 2006). Indeed, Table 18 indicates that a similar trend is seen globally with most individuals with listeriosis reported to have ≥1 predisposing condition. The impact of an underlying condition was discussed by Guerrero *et al.* (2012) who reported that mortality varied according to the underlying condition, whereas all individuals with listeriosis without comorbidities survived infection.

Goulet *et al.* (2012) calculated that the risk of listeriosis was significantly greater among those with underlying conditions, for example, when compared with persons <65 years old with no underlying conditions, those with underlying conditions such as chronic lymphocytic leukaemia had a >1000-fold increased risk of acquiring listeriosis. Those with other conditions such as liver cancer; myeloproliferative disorder; multiple myeloma; acute leukaemia; giant cell arteritis; dialysis; oesophageal, stomach, pancreas, lung, and brain cancer; cirrhosis; organ transplantation; and pregnancy had a 100–1000-fold increased risk of listeriosis (Goulet *et al.*, 2012).

It was also reported by Goulet *et al.* (2012) that clinically vulnerable groups whose underlying conditions were associated with the highest incidence of listeriosis accounted for 43% of cases and 55% of deaths, but only 1% of the total population, whereas groups with low incidence accounted for fewer cases (21%) and fewer deaths (21%), but represented 16% of the whole population. A meta-analysis on mortality risk factors for listeriosis reported that clinical predisposing factors included age ≥ 60 years, and predisposing comorbidities included non-haematological malignancies, alcoholism, chronic kidney disease, cardiovascular disease, and pulmonary disease (Huang *et al.*, 2023). The authors are in agreement with Goulet *et al.* (2012) that the population considered not at risk of listeriosis are those with no underlying condition and aged <65 years.

Table 18. Proportion of listeriosis cases among individuals with underlying conditions.

Country	Prevalence of underlying conditions among listeriosis patients
Denmark	33% of patients had ≥1 predisposing condition (Gerner-Smidt *et al.*, 2005) 30% had no underlying disease (Gerner-Smidt *et al.*, 2005)
England and Wales	90% bacteraemia patients and 74% central nervous system patients had underlying conditions (Gillespie *et al.*, 2009) 11% of patients had no underlying condition (Gillespie *et al.*, 2006)
Finland	4% of patients had no underlying condition (Suominen *et al.*, 2023)
France	65% of patients had an underlying disease (Goulet *et al.*, 2012) 73% of patients had an underlying risk factor (Goulet *et al.*, 2006)
Germany	14% of patients had no precondition (Preußel *et al.*, 2015)
Italy	90 – 92% of patients had underlying medical risk conditions (Gori *et al.*, 2020)
Netherlands	47 – 71% had ≥1 predisposing condition (Doorduyn, de Jager, *et al.*, 2006)
Romania	45% of patients had underlying diseases (Caplan *et al.*, 2014)
Spain	56% of hospitalised patients had underlying immuno-compromising conditions (Herrador *et al.*, 2019) 74% of patients had a chronic underlying disease (Guerrero *et al.*, 2012) 26% of patients were adults without predisposing factors (Guerrero *et al.*, 2012)
Turkey	89% had ≥1 underlying immuno-compromising condition (Yildiz *et al.*, 2007)
United States	41% of patients had existing health conditions or immunosuppression conditions (Barkley *et al.*, 2016) 74% of non-pregnant patients aged <65 years had an immuno-compromising condition, most commonly immunosuppressive therapy or malignancy (Silk *et al.*, 2013) 70% of non-pregnancy-associated cases had ≥1 comorbid conditions recorded (Silk *et al.*, 2012)

Salmonella and underlying conditions

Older adults in Denmark with Salmonella had higher co-morbidity than their matched reference persons (Gradel *et al.*, 2008). Cummings *et al.* (2016) reported that among individuals with salmonellosis in the US, having two or more chronic conditions was associated with a longer duration of hospitalisation and a greater disease severity.

Campylobacter and underlying conditions

Mean age of those with a severe outcome was >20 years above the mean age for all Campylobacter cases (46.2 years), this may be attributed to the higher rates of underlying medical conditions among the older population. Over the 5-year period (2013-2017) there were 30,196 confirmed cases of Campylobacter in Scotland, 12 cases died with *Campylobacter enteritis* their mean age was 75.5 years (Food Standards Scotland, 2020a, 2020b). Data from Denmark indicate that older adults with Campylobacter had higher co-morbidity than their matched reference persons (Gradel *et al.*, 2008).

4.1.16. Summary of systematic review findings

Table 19 below provides a comprehensive summary of the physiological reasons for increased susceptibility to foodborne illness among the selected clinically vulnerable groups and provides the range of prevalence for the five key pathogens of interest among the clinically vulnerable groups from the reviewed studies (*n*=138).

The table indicates that breakdown of prevalence for all five pathogens is only available according to age group. As discussed elsewhere, data detailing prevalence among multiple clinically vulnerable groups are only available for *L. monocytogenes,* it is of interest that 49 of the reviewed studies reported that 65 – 76% of listeriosis cases were among older adults.

Table 19. Summary of physiological factors contributing to increased susceptibility to foodborne infections and prevalence ranges (%) of key pathogens among clinically vulnerable groups (n=138)clinically vulnerable group (*n*=138) (*denotes no data available).

Clinically vulnerable groups	Physiological reasons for increased susceptibility to foodborne infections	*L. monocytogenes* (*n*=58 studies)	Salmonella (*n*=48 studies)	*E. Coli* (*n*=37 studies)	Campylobacter (*n*=25 studies)	Norovirus (*n*=11 studies)
Pregnancy associated cases	Pregnancy: Fully active and functional immune system at implantation, modulates as the foetus grows to protect the host and accommodate foetal development. Immune system in pregnancy is not muted. The response is pathogen specific. Intracellular pathogens like *L. monocytogenes* bypass antibodies in extracellular fluids and cross the placental barrier. Neonates: Non-specific cells such as monocytes/macrophages, neutrophils, and dendritic cells develop and mature at different times. Until ~2 months of age, macrophages can be supplemented by breast milk, but neutrophil production is too slow to fight off infections. Specialised cells are naïve and cannot recognise antigens, leading to late immune response.	37 studies: 3 – 23%	*	*	*	*
Children aged <5 years	Children aged ≥1 year experience limited immune system development, with a constrained ability to mount protective responses, leading to heightened susceptibility to infectious diseases. Immune system has limited cellular and humoral response. With age, the number of specialised cells increases, and they become more effective in producing antibodies. The maturation of immune system occurs in parallel with other environmental exposures that cumulatively shape a child's immune response to foodborne pathogens.	12 studies: 4 – 18%	34 studies: 27 – 52%	21 studies: 23 - 40%	22 studies: 56 – 74%	3 studies: 11%
Adults aged ≥65 years	Ageing leads to progressive deterioration of immune system. T-cells are highly proliferative with a lifespan of several decades, and most prone to ageing. Their production slows down with age causing the decline in IS function. 60 years of age and over is considered age of immune senescence. Chronic conditions like GI diseases, inflammatory diseases (diabetes, cancers, etc.), medication use (PPI, steroids, etc.) to treat chronic conditions increase with age leading to additional susceptibilities. Low gastric acid is not directly related to old age but related to medications used by an ageing population.	49 studies: 65 – 76%	21 studies: 9 – 17%	11 studies: 7 - 11%	9 studies: 3 – 14%	2 studies: 22%
PPI use	PPIs are a class of medications used to treat pathologies related to stomach acid production including indigestion, heartburn, acid reflux, and to prevent and treat stomach ulcers. While the acidic environment of the stomach serves as a chemical barrier against bacterial infection, PPIs prevent acid production, resulting in a decreased pH in the stomach which can lead to bacterial overgrowth, increased risk of bacterial aspiration, and changes in the gut microbiomes.	5 studies: 16 – 50%	3 studies: 9%	*	4 studies: 8 – 13%	*
Rheumatoid Arthritis	Immune system ages at an accelerated rate. T-cells undergo premature senescence and are reprogrammed to produce proinflammatory and tissue destructive responses leading to chronic immunological dysfunction. Rheumatoid arthritis therapy uses multiple immunosuppressive drugs (corticosteroids, TNF-α inhibitors, etc.) that modulates the immune system and makes individuals more susceptible to foodborne illness.	6 studies: 2 – 19%	2 studies *	*	*	*
Diabetes	High glucose and low insulin levels lead to changes in IS. Dysfunctions of both innate immunity (neutrophils and macrophages) and adaptive immunity (loss of cytokines, impaired antibody production by T-cells) contribute to weak immune response against foodborne pathogens. Autonomic neuropathy in diabetes affects upper and lower GI tract, causing heartburn, nausea, vomiting, diarrhoea, constipation, and bloating, all leading to disruption of mucosal barrier and immune system dysfunction. Microbiome dysbiosis contributes to susceptibility to foodborne infections.	19 studies: 7 – 29%	*	*	*	*
IBD/IBS/Crohn's / coeliac disease	Chronic inflammation in the GI tract leads to dysfunction of mucosal immunity affecting T-cells. Gut microbiome dysbiosis reduced the antimicrobial defences and makes the individual more susceptible to foodborne illness.	3 studies: 1 – 3%	*	*	1 study: 5%	*
Cancer	Disease biology causes immune system dysfunctions. T-cell responses are modified due to tumoral antigens. Basic diseases like Hodgkin's, T-cell lymphomas, leukaemia, myeloma, and chronic lymphocytic leukaemia cause defects in cell-mediated immunity.	27 studies: 8 – 31%	*	*	*	*

Clinically vulnerable groups	Physiological reasons for increased susceptibility to foodborne infections	*L. monocytogenes* (*n*=58 studies)	Salmonella (*n*=48 studies)	*E. Coli* (*n*=37 studies)	Campylobacter (*n*=25 studies)	Norovirus (*n*=11 studies)
Cancer treatment	Cancer treatments lead to immune system dysfunctions. Chemotherapy is cytotoxic affecting T-cells, monocytes/ macrophages, neutrophils, and GI mucosa. Chemotherapy, targeted cell therapy, and some types of radiation temporarily reduce the number of neutrophils in the blood leading to increased risks of foodborne infections.	27 studies: 5 – 14%	*	*	*	*
HIV/AIDS	HIV/AIDS causes severe immune defects. Infection causes major loss of CD4 T-cells. GI mucosa is infiltrated with cytotoxic CD8 T-cells leading to disruption of tight epithelial junctions and deterioration of mucosal immunity over time. Individuals with HIV/AIDS are extremely susceptible to foodborne infections.	8 studies: 1 – 6%	*	*	*	*
Alcohol use disorder	Alcohol consumption, even moderate, affects the frequency, survival, and function of immune cells. Smaller amounts of immune cells with impaired efficiency make alcoholics immunosuppressed at sub-clinical level, and more prone to contracting foodborne infections. Damage to mucosa further impairs T-cell mediated immune responses. Damage to GI epithelium leads to gut microbiome dysbiosis that reduces the antimicrobial defences and makes alcoholics more susceptible to foodborne infections.	11 studies: 4 – 11%	*	*	*	*
Transplant	Organ recipients receive immunosuppressive therapy to maintain graft function. The agents target various receptors on lymphocytes, inhibit immune cells, and lead to depletion of T-cells and B-cells, leading to severe dysfunction of both innate and adaptive immunity making organ transplant recipients prone to foodborne infections.	7 studies: 1 – 4%	*	*	*	*
Antibiotic use	Disrupt the gut microbiome and cause dysbiosis that leads to increased susceptibility to infections with opportunistic and foodborne pathogens.	*	7 – 17%	*	*	*
Corticosteroids use	Suppress immune system by producing anti-inflammatory proteins, and by inhibition of pro-inflammatory proteins. Reduce leukocyte migration into inflamed tissue. Mask infection symptoms. The use of glucocorticoids makes individuals susceptible to foodborne bacteria, viruses, and fungi.	11 – 43%	*	*	*	*

4.2. Review of clinically vulnerable group definitions

A total of 660 definitions relating to 'clinically vulnerable groups' and 'at-risk populations' were obtained and reviewed. These definitions came from 20 of the 36 national and global food safety organisations that were identified by the research team. Examples of how clinically vulnerable groups were defined in some of the reviewed resources included:

> *"Children under 5-years-old, pregnant women, the elderly, and people with weakened immune systems (like people with cancer or other diseases) have a higher risk of getting a bad Salmonella infection and can die if their symptoms are severe." (U.S. Food and Drug Administration, 2024).*
>
> *"Listeriosis is rare but for pregnant women, the elderly and people with weak immune systems the illness can be serious and fatal Listeria may cause pregnant women to miscarry or the baby can be born prematurely or stillborn." (Food Standards Australia New Zealand, 2024).*
>
> *"Young children, people aged 65 or over, and those whose immune systems are not working properly have a greater risk of becoming severely ill with food poisoning caused by salmonella." (Food Standards Agency, 2023).*
>
> *"Raw milk remains an inherently risky product that poses particular dangers to specific groups of people – namely children, pregnant women, older people or those who are unwell or have chronic illness." (Safefood, 2023).*
>
> *"Older adults, infants, and persons with weakened immune systems are more likely to develop a severe illness." (U.S. Department of Agriculture Food Safety and Inspection Service, 2024).*

4.2.1. Sources of definitions for review

A third of the definitions came from the US (*n*=217 definitions) (

Table 20), these included definitions from organisations including the Centers for Disease Control and Prevention (CDC), U.S. Food and Drug Administration (FDA), Food Safety and Inspection Service (FSIS), Center for Food Safety and Applied Nutrition (CFSAN), the Partnership for Food Safety Education (PFSE) and the U.S. Department of Agriculture (USDA).

As also indicated in

Table 20, the two organisations that most frequently referred to clinically vulnerable groups in their resources were Health Canada and the Food Safety Authority of Ireland (FSAI). As part of the review, 98 definitions were obtained from the UK, of these, 35 came from Food Standards Scotland (FSS), others came from the Advisory Committee on the Microbiological Safety of Food (ACMSF) (*n*=31), the Food Standards Agency (FSA) (*n*=24), UK Health Security Agency (UKHSA) (*n*=5) and the Department for Environment, Food and Rural Affairs (DEFRA) (*n*=3).

Table 20. Details of countries and organisations where definitions were obtained from (*n*=660)

Sources of definition		n	%
Countries of origin			
	United States of America	217	33%
	Ireland (ROI and NI)	123	19%
	New Zealand & Australia	104	16%
	United Kingdom	98	15%
	Canada	89	13%
	Global	29	4%
Organisation			
	Health Canada	81	12.3%
	Food Safety Authority of Ireland (FSAI)	72	10.9%
	Centers for Disease Control and Prevention (CDC)	55	8.3%
	Safefood	51	7.7%
	New South Wales Food Authority	50	7.6%
	Food Safety and Inspection Service (FSIS)	47	7.1%
	Food Standards Australia New Zealand (FSANZ)	46	7.0%
	U.S. Food and Drug Administration (FDA)	45	6.8%
	Food Standards Scotland (FSS)	35	5.3%
	Center for Food Safety and Applied Nutrition (CFSAN)	33	5.0%
	Advisory Committee on the Microbiological Safety of Food (ACMSF)	31	4.7%
	World Health Organization (WHO)	29	4.4%
	The Partnership for Food Safety Education (PFSE)	28	4.2%
	Food Standards Agency (FSA)	24	3.6%
	Health Products and Food Branch	8	1.2%
	U.S. Department of Agriculture (USDA)	8	1.2%
	UK Health Security Agency (UKHSA)	5	0.8%
	Ministry for Primary Industries (NSW)	5	0.8%
	Department for Environment, Food and Rural Affairs (DEFRA)	3	0.5%
	Department of Agriculture, Water, and the Environment	3	0.5%
	International Food Protection Training Institute (IFPTI)	1	0.2%

As indicated in Figure 2, 14% of the reviewed documents that defined clinically vulnerable groups did not have a publication or update date available. Of the remainder, 42% were published or updated in the previous 5 years, 291 of the definitions were in resources that were published up to 24 years ahead of the review.

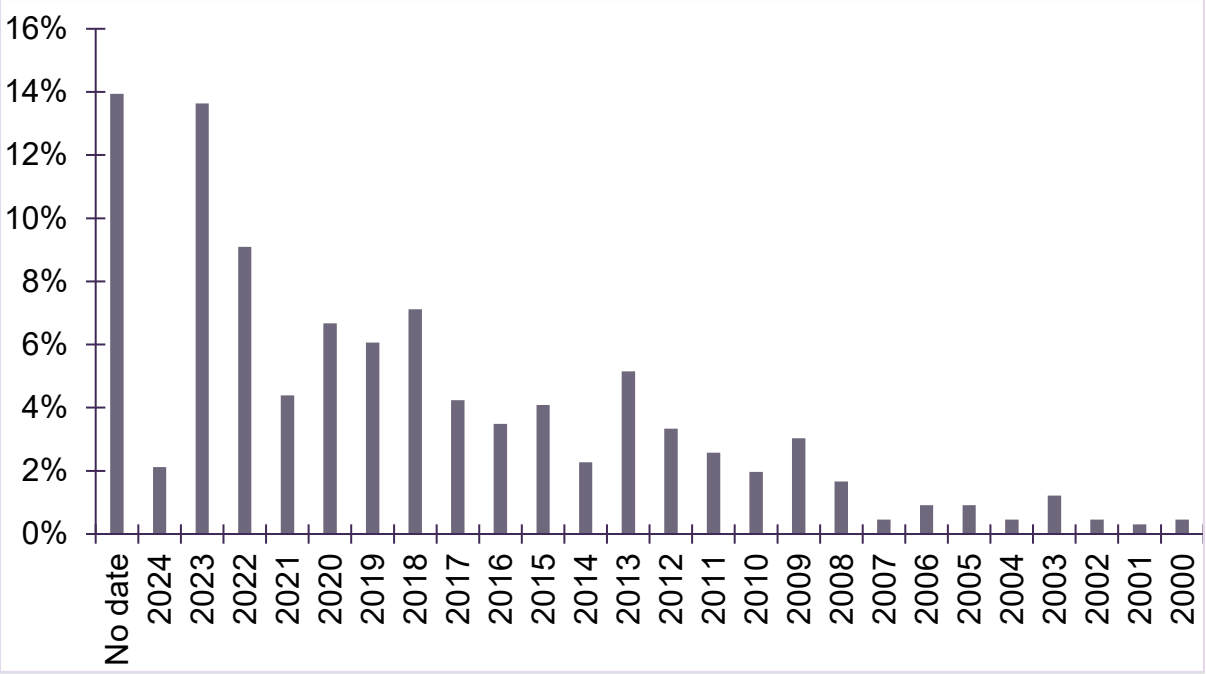


Figure 2 Dates of publication/review (*n*=660).

The most common types of resources that definitions were obtained from included consumer advice (32%), general information pages (29%) and reports (such as risk assessment) (27%). Other resources included guidance for industry, healthcare, or educational institutions (Table 21).

Table 21. Types of resources definitions were obtained from (*n*=660).

Resource type	n	%
Consumer advice/information	213	32%
General information	191	29%
Report (Public health reports/Risk Assessment)	177	27%
Guidance/information for industry (food manufacturing and food service)	58	9%
Guidance/information for healthcare (professionals/institutions/authorities)	21	3%
Guidance/information for education (schools/teachers/childcare)	6	1%
Policy document	6	1%

4.2.2. Inclusion of clinically vulnerable groups according to pathogens

Of the 660 definitions relating to clinically vulnerable groups and at-risk populations that were reviewed, the pathogen most frequently referred to was *L. monocytogenes,* with 293 of the definitions (44%) specifically referring to the pathogen. As indicated in Table 22, 140 definitions (21%) referred to Salmonella, fewer referred to *E. coli* (*n*=90/14%), Campylobacter (*n*=60/9%) and norovirus (*n*=56/8%). One hundred and forty-nine of the resources that defined clinically vulnerable groups did so in relation to generic foodborne illnesses or referred to "food poisoning".

Table 22. Foodborne pathogens referred to in relation to clinically vulnerable groups (*n*=660)

Pathogens	Number of definitions	%
L. monocytogenes	293	44%
Salmonella	140	21%
E. coli	90	14%
Campylobacter	60	9%
Norovirus	56	8%
Non-specific foodborne pathogens	149	23%

Among the groups defined as being clinically vulnerable, one or more of the groups collectively described as the YOPI fraction (young (0-5 years), older (65+ years), pregnant, and immunocompromised) (Denayer *et al.*, 2017; Gray *et al.*, 2024) were included in 100% of the definitions.

As illustrated in

Table 23, older adults were most frequently referred to, which were included in 96% of the definitions. Nearly three-quarters (72%) of the definitions referred to people with weakened immune systems, 64% referred to pregnant individuals and/or their unborn children, 52% referred to children and 35% referred to neonates or newborns. Indeed, these groups do include persons that are often highly susceptible to infection and generally suffer much more serious illness than other members of the community.

Table 23. Groups acknowledged as being clinically vulnerable to foodborne pathogens in definitions (*n*=660).

Clinically vulnerable groups	Number of definitions	%
Older adults	633	96%
General weakened immune system	472	72%
Pregnant individuals/unborn infants	422	64%
Children	345	52%
Neonates / newly delivered infants	230	35%
People with cancer (unspecified)	75	11%
People with HIV/AIDS	71	11%
People with diabetes	68	10%
Other chronic conditions (e.g. cardiovascular, kidney, liver disease)	66	10%
Transplant recipients	54	8%
People with cancer (immunosuppressive treatment)	39	6%
Other medication related (e.g. steroids)	26	4%
People with alcohol use disorder (incl. alcoholic liver disease)	18	3%
People prescribed proton-pump inhibitors	8	1%
People with cancer (radiation therapy)	7	1%
Individuals with IBD/IBS/Crohn's	6	1%
Other autoimmune diseases (e.g. lupus)	5	1%
People with Multiple Sclerosis	1	0%
People with Rheumatoid Arthritis	0	0%
Eating disorders (malnourished)	0	0%
Obesity	0	0%

Further breakdown of the data as indicated in Table 24 and in Appendix 6 indicates that 40% of the definitions specifically referred to the risk of listeriosis among pregnant individuals (40%), older adults (37%) and those with weakened immune systems (34%).

Table 24 Definitions that referenced clinically vulnerable groups in relation to specific pathogens.

Clinically vulnerable groups	*L. monocytogenes* (*n*=293)	Campylobacter (*n*=60)	*E. coli* (*n*=90)	Salmonella (*n*=140)	Norovirus (*n*=56)	Non-specific foodborne pathogens (*n*=149)
Pregnant individuals/unborn infants	90%	33%	27%	29%	11%	63%
Older adults	83%	70%	79%	86%	29%	81%
General weakened immune system	77%	37%	49%	70%	30%	62%
Neonates / newly delivered infants	55%	17%	12%	29%	4%	15%
People with cancer patients (unspecified)	15%	8%	3%	9%	0%	9%
HIV/AIDS	14%	13%	1%	7%	0%	11%
People with diabetes	13%	7%	1%	4%	0%	13%
Other chronic conditions (e.g. cardiovascular, kidney, liver disease)	12%	7%	1%	3%	0%	12%
Transplant recipients	11%	5%	2%	6%	0%	8%
Children	8%	67%	90%	75%	27%	80%
People with cancer (immunosuppressive treatment)	8%	7%	2%	1%	0%	7%
Other medication related vulnerabilities	6%	3%	0%	0%	0%	3%
Individuals with alcohol use disorder (incl. alcoholic liver disease)	5%	0%	0%	0%	0%	3%
People with IBD/IBS/Crohn's	1%	0%	0%	0%	0%	1%
People with cancer (radiation therapy)	1%	0%	0%	0%	0%	3%
Other autoimmune diseases	0%	0%	0%	1%	0%	2%
People prescribed PPIs	0%	2%	0%	2%	0%	1%
People with Multiple Sclerosis	0%	0%	0%	0%	0%	1%
People with Rheumatoid Arthritis	0%	0%	0%	0%	0%	0%
Eating disorders (malnourished)	0%	0%	0%	0%	0%	0%

Older adults

Older adults were the group most frequently referred to in relation to clinically vulnerable groups at risk of foodborne illness (96% of all definitions), furthermore, as indicated in Table 24, in relation to each of the five pathogens of interest, older adults were most frequently referred to in relation to Campylobacter (70%), Salmonella (86%) and non-specific foodborne pathogens (81%). Although 90% of sources referring to listeriosis referred to pregnant individuals and their unborn babies, 83% of definitions for clinically vulnerable groups relating to listeriosis referred to older adults.

Various terms were used to refer to older adults including seniors, elderly, and ageing populations. Of the 559 definitions that referred to older adults, 25% referred to a specific age, as indicated in Figure 3, the most common age banding given for older adults was ≥65 years (70%), 18% referred to ≥60 years.

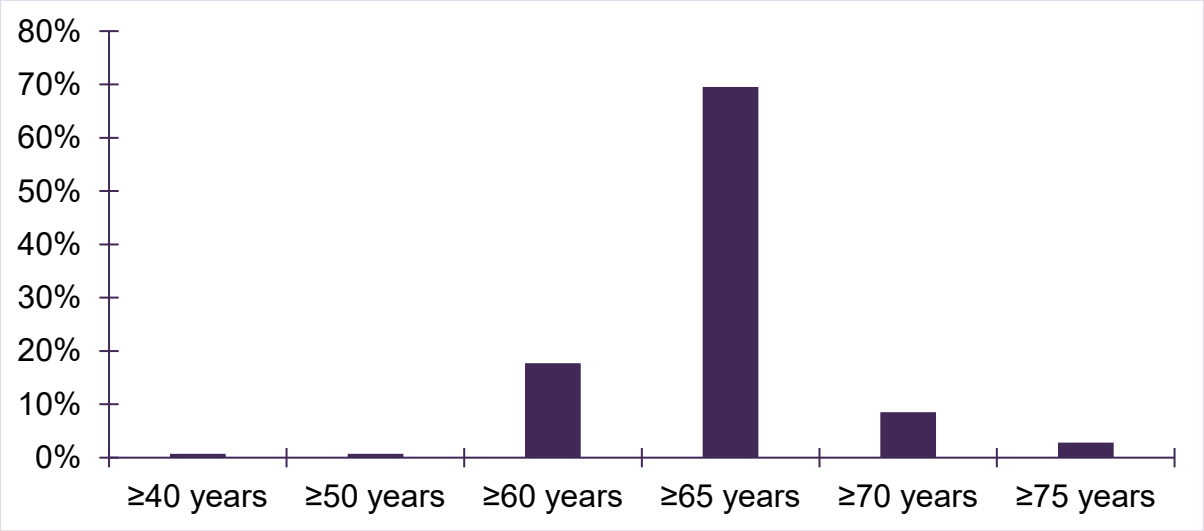


Figure 3. Age groups given for older adults (*n*=141).

Children

Children were more commonly referred to in relation to *E. coli* (90%), Salmonella (75%), and non-specific foodborne illness (80%). Children were only referred to in 8% of definitions relating to *L. monocytogenes* and 27% of definitions regarding norovirus. A total of 339 definitions referred to children, 32% of these specified an age. As indicated in Figure 4, the ages given varied, however the majority (80%) referred to children under the age of five years old.

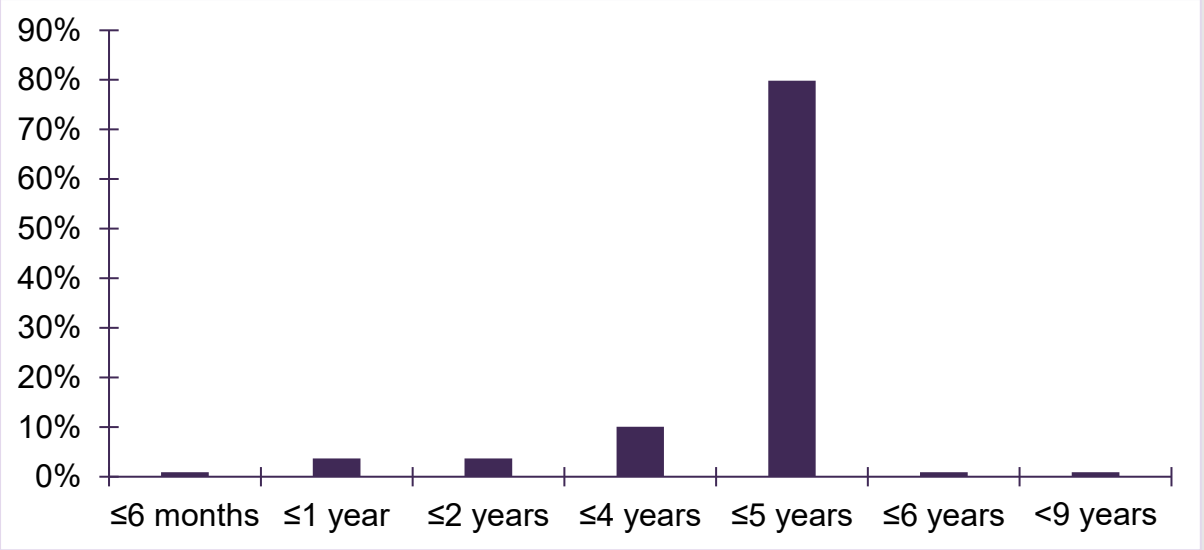


Figure 4. Age groups given for children (*n*=110).

4.2.3. Inclusion of information detailing why certain groups are clinically vulnerable to foodborne pathogens

Most definitions were generic and referred to multiple groups. Six percent of definitions (*n*=41) were specifically targeting a defined clinically vulnerable group and 8% of definitions (*n*=51) gave specific advice for different clinically vulnerable groups, such as specific food products that pregnant individuals should avoid.

Of the 660 definitions reviewed, it was determined that 42% did not provide context as to why individuals are vulnerable or at increased risk of foodborne illness, 49% simply stated that it was *'because of a weakened immune system'.* Sixty-two definitions (9%) provided context, the majority of these referred to children, pregnant individuals, and people receiving chemotherapy treatment, for example:

> *"Food poisoning can be especially severe for infants because their digestive and immune systems are immature." (NSW Food Authority, No date).*
>
> *"Young children make less stomach acid that kills harmful bacteria, making it easier for them to get sick." (U.S. Food and Drug Administration, 2022).*
>
> *"Your baby or toddler is at increased risk for foodborne illness. Young children do not have fully developed immune systems. They may be more likely to become ill, have serious complications and have a harder time getting well." (Partnership for Food Safety Education, no date).*
>
> *"When you're pregnant, hormonal changes in your body lower your immune system which can make it harder to fight off illness and infection." (New South Wales Food Authority, No date).*
>
> *"You and your growing fetus are at high risk from some foodborne illnesses because during pregnancy your immune system is weakened, which makes it harder for your body to fight off harmful foodborne microorganisms Your unborn baby's immune system is not developed enough to fight off harmful foodborne microorganisms. For both mother*

> *and baby, foodborne illness can cause serious health problems — or even death.” (Center for Food Safety and Applied Nutrition, no date).*
>
> *"If you are a cancer patient, your healthcare provider may have recommended that you receive chemotherapy, radiation, or other treatments to help fight your disease. A weakened immune system can be a side effect of these types of therapies. A properly functioning immune system works to clear infection and other foreign agents from the body. However, cancer and its treatments can weaken your immune system, making you more susceptible to many types of infections." (U.S. Department of Agriculture Food Safety and Inspection Service, 2020).*

Very few described why older adults are at an increased risk of foodborne illness, for example:

> *“Among the elderly, the risk increases as individuals age, i.e., as compared to healthy individuals 40 to 59 years of age, Canadian data show that persons aged 65 to 69 years of age have a 4-times increased risk, while those aged 75 to 79 years of age have nearly a 9-times increased risk (PHAC, 2009b).”*

Although these rare examples do provide some context, it is unclear to what extent consumers understand the details, and therefore, we believe this merits further exploration.

Most definitions (64%) did not provide references or sources of information, 19% referred to previous research with references, the remainder referred to other information sources such as organisation landing pages.

4.3. Expert panel consultation regarding definition of clinically vulnerable groups

During the three expert panel consultations with the twenty experts (details of which can be seen in Appendix 4), the expert panel congratulated Food Standards Scotland on taking the initiative to commission this much needed work. They expressed their enthusiasm in having the opportunity to participate in the consultation and discuss the findings. The expert panel agreed that the research report merits publication and encouraged the publication of detailed reports specific to some of the clinically vulnerable groups identified in the report, particularly ageing adults, and other less acknowledged groups such as PPI users and people with IBD. The expert panel commended the rigour and comprehensiveness of the research and highlighted the significance and impact of the findings.

Several key themes arose from the discussions, these included considerations regarding neglected or emerging clinically vulnerable groups and recommendations for future surveillance, the roles and responsibilities of different stakeholders in communicating with clinically vulnerable groups, and recommendations for the future.

4.3.1. Neglected clinically vulnerable groups

The experts indicated several categories of vulnerable patients that could be considered in future definitions. Patients suffering from long COVID was indicated as an emerging vulnerable population, and future surveillance should consider this group. PPI users should be addressed as a clinically vulnerable group as there is compelling evidence of increased foodborne illness risks. PPI prevalence is

increasing in ageing adults, the experts considered if PPI users would consider themselves to be at risk. Furthermore, redefining the clinically vulnerable groups according to the specific medications, such as PPIs, immune suppressors, steroids, and others, rather than according to their age or conditions, was recommended as a more effective way of communicating to these groups.

In general, the lack of data was acknowledged for most foodborne pathogens, except for *L. monocytogenes*. The need for improved surveillance and the necessity to collect more information about the underlying conditions and the medications from patients was highlighted. It was suggested that linking foodborne illness data with medical records would give much needed insights to better understand the vulnerabilities relative to general populations.

More data is needed to better characterise the age groups both in the older adults and the children categories. The current cut-off ages remain a point of discussion among the experts. There was no consensus among the experts of specific age groups relating to children or ageing adults. However, it was acknowledged that current age groups reflect the categories that are used in epidemiological studies and/or retirement ages.

A gradient of vulnerability was suggested to describe the age-dependent changes. Immunological variations are individual and determined by co-morbidity and the use of medication that modify the susceptibility to foodborne illnesses.

The experts recommended future considerations of several sociodemographic and behavioural factors when developing future food safety definitions. Recommendations were also made for the research community to included low sociodemographic strata, ethnicity factors, immigrant and indigenous groups, and inclusion of developing regions in future reviews of prevalence data.

It was acknowledged that to provide meaningful data for FSS, the research excluded data from developing countries, however it was recommended that undertaking a similar review in developing countries was suggested to give a comparison between developed and developing countries. The potential impact of malnutrition upon susceptibility to foodborne illness could be explored in this work. In the current review, prevalence of foodborne illness among malnourished individuals were not obtained.

Experts acknowledged that all prevalence data that were associated with specific behavioural factors were excluded, however it was suggested that research is required to explore the potential impact of socio-economic and lifestyle factors upon the risk of foodborne illness. Food Standards Scotland have already recognised the importance of behavioural factors and with the Scottish Environment, Food and Agriculture Research Institutions, have funded a research fellowship to determine the lifestyle factors which cause particular members of the older population to become ill with foodborne disease (SEFARI, 2023).

Several emerging pathogens were mentioned including Hepatitis E and *Vibrio* spp., that could be considered in future work regarding clinically vulnerable groups.

4.3.2. Communication to different stakeholders

The experts agreed that different versions of communication about vulnerabilities are needed for different groups. The majority thought that definitions by pathogen may not be efficient and could introduce more confusion especially for the consumers. A tiered approach with the most detailed technical information for health professionals was suggested.

While the experts highlighted the importance of understanding consumer perspectives, they thought that the simple summaries for the clinically vulnerable groups that emphasise the reasons for vulnerability and highlight the specific conditions and medications, rather than generalised information were thought to be more relatable to consumers and may potentially lead to improved food safety compliance. Explaining to the clinically vulnerable groups what the risks look like in practice, and clarifying that appropriate management of their conditions, such as diabetes and others, may lead to reducing their risk of foodborne infections. Offering alternative foods to high-risk options was recommended.

Responsibility in conveying information to clinically vulnerable groups was further discussed, and healthcare providers were identified as important sources of any information about food safety risks due to medication use. The patients would benefit if their medical doctors, or specialists explained the risks from foodborne pathogen infection if they are prescribed PPIs, immune suppressants, or steroids for their conditions.

The experts discussed the use of advanced and generative technology for food safety communication to clinically vulnerable groups and individuals. While they acknowledged technology may play an important role in the future, it was agreed that some clinically vulnerable groups remain reliant or simply prefer printed materials and simple digital messaging.

Timing of food safety messaging to clinically vulnerable groups was brought up by the experts as both a challenge and an opportunity. Vulnerable patients would benefit the most from timely information delivered while they are in contact with the healthcare providers who are addressing their health conditions. This may present as a difficulty due to multiple other communications that the patients receive to help them through the healing and health management process. The patients may be overloaded with information and not open to food safety messages. The high workload among healthcare providers was also acknowledged as a challenge to adding the responsibility for food safety communication to their schedules. A multidisciplinary approach in which multiple healthcare professionals (e.g., doctors, nurses, dietitians, pharmacists, etc.) share the responsibility in delivering the consistent food safety information to the patients would ensure the awareness of the risks among clinically vulnerable groups.

4.3.3. Considerations for future definitions

During the expert panels, it was widely discussed that to enable a clear decision on the need for separate definitions for each of the pathogens of interest, there is a need for enhanced surveillance for Campylobacter, *E. coli,* Salmonella, and norovirus. It was suggested that there may be merit in having a distinct definition for listeriosis as more data are available in relation to prevalence of foodborne illness caused by *L. monocytogenes* among the clinically vulnerable groups. It was also suggested that having separate definitions per pathogen may be too confusing for consumers. For example, consumers may not need to know which foodborne pathogen they are at an increased risk of, they need to know that they are at an increased risk, the reasons why, and be aware of appropriate risk reducing behaviours.

4.4. Discussion groups with consumers to consider food safety messaging to clinically vulnerable groups

As outlined in section 3.6, discussion groups were undertaken to explore preferred methods of communicating who the clinically vulnerable groups to foodborne illness are. The in-person discussion groups (*n*=6) were undertaken in various locations through Scotland with individuals over the age of 65 years and individuals who support people over the age of 65 years (*n*=50).

4.4.1. Perceptions and preferences of different risk statements among people over the age of 65 years

During the discussion groups, participants were presented with the three different risk statements regarding clinically vulnerable groups to listeriosis. These ranged from the shortest and the least complex statement which was a variation on the standard YOPI categories (Figure 5), an extended YOPI classification which defined specific chronic illnesses and treatments/medication identified in this report that result in reduced immune function (Figure 6) and a statement providing extended YOPI categories specifically defining why the listed groups are clinically vulnerable to foodborne illness which contained the most information (Figure 7). The statements were colour coded and presented to the participants in the ascending order of complexity.

Perceptions regarding the short risk statement

The first statement reviewed during the 6 discussion groups was the variation on the standard YOPI categories (Figure 5).

> Some people are more vulnerable to listeria infections, including those over 65 years of age, pregnant individuals and their unborn babies, babies less than one month old and people with weakened immune system.

Figure 5. Pink risk statement (a variation on the standard YOPI categories) presented to the focus group.

Although some participants liked the simplicity of the pink statement (Figure 5), the consensus among the groups was that the statement was *"too generic"* and did not provide sufficient information. Several participants suggested that the generality of it would result in it being disregarded. This can be illustrated by the comment made by a participant in group 3:

> *"I feel I would disregard it… I think it's because it's so general. There's so many things that they warn you about, it's if you're pregnant, if you're over 65, and really, I would just look at that and think, "Oh yeah, just another one"." (Group 3, Respondent 3)*

This is consistent with the opinions expressed by the experts during the three panel consultations who concluded that the risk statements that contain only generic information may not be relatable to the clinically vulnerable groups (section 4.3).

Perceptions regarding the extended risk statement

The second statement reviewed during the discussion groups was the extended YOPI classification which defined specific chronic illnesses and treatments, or medication identified in this report that result in reduced immune function (Figure 6).

> Some people are more vulnerable to listeria infections due to reduced immune function, these include:
> - Pregnant individuals and their unborn babies, and babies less than two months old.
> - People with chronic illnesses such as cancer, diabetes, inflammatory bowel disease, rheumatoid arthritis, or other autoimmune conditions.
> - People receiving treatment and medications such as chemotherapy, proton pump inhibitors and immunosuppressants.
> - People over 65 years of age.

Figure 6. Blue risk statement (extended YOPI categories defining chronic illnesses and treatments that result in reduced immune function) presented to the focus group.

In comparison to the pink statement (Figure 5), the blue statement was more widely discussed. Many preferred the inclusion of specific conditions and medications that

result in reduced immune function. Some suggested that this would catch their attention as is refers to specific conditions.

> *"I would take far more attention of this because it mentions several things that are important to me. I'm on immunosuppressants. So, there are things there that trigger me so I would immediately read that with more interest and take more consideration of it." (Group 3, Respondent 5).*

> *"And the list of all of the people who can be affected, detailed list, because I don't think I would have associated diabetes when I read the first one and I have a friend with diabetes, and I definitely didn't know that." (Group 4, Respondent 5).*

However, several individuals suggested that they may not take notice and did not perceive themselves to be vulnerable, even though they had underlying conditions listed in the risk statement. This was often accompanied by the false sense of acquired immunity, or perceptions of invulnerability and optimistic bias. As previously discussed, such perceptions may undermine food safety messaging (Evans & Redmond, 2019) and future messaging needs to combat such perceptions.

> *"Well, I've got diabetes Type 2, but it doesn't worry me… Well, if you've eaten in some of the places in the world, I've eaten you become immune to these sorts of things." (Group 1, Respondent 5).*

> *"I'm over 65. And I think you think, "Well I'm careful so it won't happen to me. I wash my hands; I look after my food." And that may be why, I don't know, people over 65 maybe are more susceptible, like living on their own, having foods that have maybe got out of date because they can't afford to, you know, buy things frequently or just because they don't eat it fast enough. I don't know if that's what makes people over 65 more vulnerable." (Group 3, Respondent 4).*

> *"Well, I tick a lot of those boxes. I didn't realise that. Does it make me think that I am more susceptible? Well, I'm going to say no to that" (Group 5, Respondent 3).*

> *"…if somebody who's diabetic, that's a healthy diabetic, would read it and think, that's rubbish I'm diabetic, I'm fine, so it's not that easy. I know it's not that easy, but I think that has to be addressed somewhere" (Group 6, Respondent 3).*

Although some participants acknowledged the need for more information regarding clinically vulnerable groups, they were concerned that the level of information in the blue statement would prevent people from engaging with it:

> *"The blue statement tells it like it is. I find that that pink one is basically sugar-coating things, isn't it, and people need to know this... I think between the two statements, one is shorter and easier to read, who is going to take the time to read the whole of the blue. So, it's, there's more information in the blue but many people get that, they won't get past the first paragraph, and they will just go hmm and wander off." (Group 5, Respondent 5).*

It was concluded that although the blue statement provided more information about who's vulnerable, it did not make individuals over the age of 65 years, with listed underlying conditions believe that they were susceptible to foodborne illness.

> *"It's obviously got a lot more information there. I still don't feel vulnerable." (Group 6, Respondent 1).*

> *"Doesn't make me feel more vulnerable either." (Group 6, Respondent 2).*

Perceptions regarding the descriptive risk statement

The final risk statement that was discussed during the six discussion groups provided an the extended YOPI categories which specifically defined why the listed groups are clinically vulnerable to foodborne illness (Figure 7).

Certain groups are more vulnerable to listeria infections:

- **Pregnant individuals, unborn, and newborn babies.** During pregnancy, the immune system undergoes changes to support the foetus, allowing bacteria to bypass antibodies, cross the placenta and infect the baby.
- **People with chronic conditions.** People with cancer, diabetes, inflammatory bowel disease, rheumatoid arthritis, or other autoimmune conditions have impaired white blood cell production making it harder to fight infections.
- **People receiving chemotherapy treatment and immunosuppressants.** These treatments reduce the number of immune cells in the blood stream available to fight infection.
- **People using proton pump inhibitors.** Proton pump inhibitors, used to treat heartburn block stomach acid production, which allows bacteria to grow and cause infections.
- **People over 65 years of age.** Ageing weakens the immune system, leading to fewer antibodies and increased susceptibility to infections. In general, the greater the age the higher the susceptibility. Additionally, older adults often have more chronic conditions and need more medications, which further increases their susceptibility.

Figure 7. Yellow risk statement (Extended YOPI categories defining why the listed groups are clinically vulnerable) presented to the focus group.

Although some believed the description to be too long, others felt it to be important and informative. It was discussed that the visual presentation of the information (bold and bullet pointing) made the statement accessible and allowed for a quicker summary by the individuals who felt that the statement was too long:

> *"Sorry, I fell asleep. It's far too long." (Group 2, Respondent 3).*

> *"I find it very interesting actually, very informative. What you're saying is all these conditions have impaired white blood cell production, which I just find interesting finding out things like that." (Group 3, Respondent 4).*

> *"I think it very much depends on the communication. I like the blue one because it's quick and easy but it's still comprehensive, and there is lots of things in it that I can go and look up. The yellow one is obviously much better but it's longer and people do tend to have very short attention spans these days. So, you might not read it and then not go and investigate." (Group 3, Respondent 5).*

> *"It's comprehensive, isn't it but you can pick it, it's got the highlighted bits." (Group 5, Respondent 3).*

> *"So, you can look at the bullet points and say well, that doesn't affect me, that would affect me… and then you don't waste time reading all the bits that you don't need, you know, and you just go straight to the one that you do." (Group 5, Respondent 6).*

> *"I like it because it explains why these people are vulnerable." (Group 2, Respondent unknown).*

Many of the participants expressed that they have related to the statement and were surprised to learn that they were at an increased risk of foodborne illness

> *"So that's new to me, a person over 65... I didn't know that." (Group 2, Respondent 4).*

> *"I didn't know that. I knew that pregnant had to avoid soft cheese and all that sort of stuff because of listeria but I didn't realise that people over 65 were more susceptible." (Group 4, Respondent 5).*

> *"I fit three of those, and my husband and I between us fit four of those. I'm not pregnant. It's the only one I'm excused from [laughter], but we fit four of those. Now whilst I know that he is more vulnerable, I've always assumed he's vulnerable because he's got cancer and he's having ongoing treatment. I've never ever applied that to me, and I've got three things there that applies that to me. So perhaps I ought… I think information is power. If you don't know something, you can never choose to take steps whereas if you do know something, you could either – react by ignoring it or you can act… you have a choice. Yes, you have a choice about how you deal with the situation, and I think, always think, knowledge is power. It does have a scary side, no question but that's just what it is." (Group 5, Respondent 3).*

> *"I have never thought I was vulnerable, but I think as you get older, you don't really want to think you're getting older. You still think you've still got that same constitution as you had when you were young but it will make me … because I'm a wee bit, let's say, you know, I'm a bit kind of slapdash with things, that is, like, keeping temperature but it will make me think about it more carefully in future and I think that's education, and I'm quite aware of the connection" (Group 5, Respondent 6).*

Many believed that the yellow and blue statements could be used depending on the audience and situation. Nevertheless, one participant did not believe the statements to be educational, with others disagreeing with the statement suggesting that the statement was educational and necessary:

> *"Unfortunately, all I can see is that you're going to scare people. Whatever you want to do, its scaring people, they're just going to go, what?" (Group 5, Respondent 7).*

> *"It's the education that's necessary." (Group 5, Respondent 6).*

4.4.2. Awareness of susceptibility to foodborne illnesses

During the discussion groups, participants were asked about the susceptibility to foodborne infection and their immune systems. Many identified pregnant women and people receiving chemotherapy as being clinically vulnerable, however other groups were seldom acknowledged, many had not previously considered themselves as being susceptible and indicated that they weren't aware that the immune system changes with age:

> *"When you get older, your system doesn't have the ability to fight illness as well as it used to. Not at the end of our 50's, over 60, 65, 70, kind of just your body just… like cars aren't made to last 70, 80, 90 years, our bodies start to run down and their ability*

to fight, our immune system isn't … no matter how well you eat, your immune system is not as rigorous as it was in your 20's and 30's." (Group 2, Respondent 2).

"I find that quite worrying, the new data statistic. I've never considered myself high risk. Well, maybe I am, I've just turned 70 so maybe I'm high risk." (Group 2, Respondent 8).

"I wasn't consciously aware that your immune system declines with age. I know your whole body begins to collapse and different things, but I wasn't particularly aware that the immune system specifically tended to decline with age." (Group 3, Respondent 4).

"I think, to be honest, the immune system is something we really don't think about at all. Unless you have something specific. But, you know, for most people they'll think of flus and colds and cuts and bruises but the last thing they'll think about is the immune system. What surprised me with my learning is just how much our health is affected by our immune system. You know, I never knew that arthritis was an immune system thing, you know, until I got it. So, I think people are very unaware of what the immune system actually is or does." (Group 3, Respondent 5).

"Yeah, cos you're getting older and it's not just your immune system, your whole body is reducing to fight you know, it's been fighting for in my case, 67 years, it's been fighting and that's a long time. So (referring to an illness when younger) for one day or two, it's now three or four or more, so your immune system is tired, worn out." (Group 4, Respondent 10).

"I suppose the older you get you're more vulnerable to everything so it's just one of those things, I guess. It's not something I've really thought about… To be honest I don't feel vulnerable yet but then, yeah, first time I was aware of things when I was pregnant and things I would obviously be much more careful than... and with the grandchildren when they've been tiny, you're obviously very careful. But I don't feel vulnerable myself but whether that's because you don't like to admit that you're getting older and of that generation, I don't know." (Group 6, Respondent 1).

In relation to awareness of susceptibility, some discussions related to being in denial about ageing and not feeling vulnerable:

"I think you're aware that ageing, not just it weakens the immune system it weakens everything doesn't it? It is denial... I'm not ready yet to accept that. Yeah. Denial." (Group 6, Respondent 1).

"I was surprised when you said the percentage of people, older people, who are affected by Listeria, I don't feel vulnerable either. 'Cause I think I'm careful about what I eat." (Group 6, Respondent 2).

One participant indicated awareness due to underlying conditions:

"No, mine isn't (referring to their immune system). It's the diabetes, I'm prone to infections, even a cat scratch takes ages to heal, I heal very slowly, I've lost two toes, I don't want to lose anymore." (Group 4, Respondent 2).

4.4.3. Appropriate terminology

During the discussion groups, many discussed the appropriate terminology to refer to people over the age of 65. Regarding the term "older adult", some didn't have an opinion on the term, whereas others felt that it wasn't specific enough to identify the clinically vulnerable group. Many indicated that it was important the term used wasn't patronising, in general people were happy with specifically referring to age.

> *"But 'older adults' is not specific enough. You've said, 'Over 65', why are we older adults? To be a 50-year-old is probably an older adult really." (Group 1, Respondent 2).*

> *"Older adults - somebody that's older than yourself." (Group 1, Respondent 5).*

> *"My mum was 93 when she died, but she wasn't old." (Group 1, Respondent 4).*

> *"If that's what you're including, people over 65, then it can say 'People over 65'." (Group 1, Respondent 2).*

> *"And 'pensioners', people are getting their pensions at all different times now so you can't say 'pensioners' because somebody may not have it yet or may not get it until they're 70, so I think the 65 is fine." (Group 4, Respondent 2).*

> *"It's difficult. It's an arbitrary number 65. Because there's old, old 50-year-olds and there's really young 90-year-olds. So, it's where the individual fits." (Group 5, Respondent 4).*

> *"I don't want a patronising term. Drives me up the wall 'Elderly'. 'Older people', well, how old? I mean, some people think they're old and they're 40. How do you define it? That's a proper category (referring to people over 65)." (Group 5, Respondent 3).*

The participants acknowledged that it is important to recognise the differences among people over the age of 65, particularly the presence of other underlying conditions:

> *"Because if you're over 65, you know in your own life that you can't quite do what you used to do necessarily. You know that things have changed but if you don't have any other condition, then so what, I'm over 65. That doesn't speak to me. And I actually don't like it, as if all older people are the same. We're not all the same." (Group 2, Respondent 7).*

With regards to clinically vulnerable groups, discussion regarding the use of appropriate terminology extended to the use of appropriate imagery to represent people over the age of 65. Indeed, a previous study with people receiving chemotherapy treatment has reported that pictures intended to exemplify people with cancer or receiving chemotherapy were particularly disliked by focus group participants because they wanted to relate to the images (Evans & Redmond, 2022).

> *"I think the image of older people has changed a lot anyway. So, to come to that point about what are you going to represent older people with, you know, people with sticks or whatever, I think we have aged as a society much more kindly than we did fifty or sixty years ago. So, I think that image of how you're going to represent older people has to reflect that." (Group 1, Respondent 3).*

> *"The problem… Well, like we've been saying we all feel, you know, reasonably good for our ages, so if you put an 80-year-old up there doddering about and saying, "Be careful about your immune system," you'd probably think, "That's not me." Whereas if you see someone like yourself… Because she looks great (referring to another participant) … And you think, "My gosh, my immune system – I am also vulnerable." I think that would have more of an impact." (Group 3, Respondent 3).*

> *"It's not a flippant thing, it's quite a serious issue. So yes, I think if you're going to put photos and stuff in, they need to be relevant." (Group 5, Respondent 3).*

Discussions also considered the opportunity for visual aids to enable people to recognise that they may be at an increased risk of foodborne illness due to age, medication or underlying condition.

4.4.4. Trusted sources of information

The discussion groups also considered who would be trusted sources disseminating information regarding clinically vulnerable groups. Although there was some mistrust regarding the UK government, government departments such as Food Standards Scotland and the UK Food Standards Agency were generally trusted.

> *"I certainly wouldn't trust the British Government because they don't know their arse from their elbow." (Group 1, Respondent 5).*

> *"And I would probably trust the Food Agency." (Group 5, Respondent 3).*

Five of the six groups indicated that the National Health Service (NHS) would be a trusted source of information, however a few participants in one discussion group believed that the NHS was not the most trusted source of information, this was due to the publication of the infected blood inquiry report the week prior to the discussion group (Infected Blood Inquiry, 2024). Although the NHS was trusted overall, some felt that specific healthcare professionals were best placed as trusted advocates for communicating such information such as pharmacists.

> *"I would to a certain extent trust the NHS." (Group 1, Respondent 5).*

> *"I would think the medical profession." (Group 2, Respondent 8).*

> *"Unfortunately, you can't have the NHS doing it because of the inquiry that's just going on… That they lied and lied and lied and lied and lied. You can't have somebody sitting there saying, I'm from the NHS, I'm not decrying the NHS, but you can't have somebody saying, I'm from the NHS and I'm telling you, that's what they did to the blood scandal" (Group 5, Respondent 7).*

> *"Yes. I think quite often pharmacists will say to people, you know, "Why are you taking this?" or "Why have you been given this?" They've not got quite the same stake in it as the person who's prescribing it, you know? And they know a lot about how drugs interact and that sort of thing." (Group 3, Respondent 4).*

> *"I think the pharmacists have become since COVID so much more the first port of call for people that are unwell." (Group 3, Respondent 3).*

Charities that support individuals with specific underlying conditions such as Cancer Research UK and Diabetes UK, were discussed as being trusted sources of information, particularly if they partnered with Food Standards Scotland or Food Standards Agency to communicate the risk of foodborne illness. Similarly, organisations that support people over the age of 65 would be trusted sources of information such as Age UK, Scottish Men's Sheds Association, University of the Third Age, and Scottish Women's Rural Institutes.

Many participants indicated that they would be comfortable with accessing information online, but acknowledged the importance of source checking due to misinformation and conspiracy theorists:

> *"I'm very sceptical about what's on the internet because you have to check the source somehow and most of us don't. So, it needs to be on the internet because that's the go-to, but it needs to be from a validated place, but I think television advertising, because most people have the television on, not everybody, but most people have it on, so it's sort of campaign on the television maybe." (Group 5, Respondent 3).*

"You've lots of American conspiracy theories with all kinds of nonsense." (Group 3, Respondent 4).

"I think more and more people are going to be ignoring social media; it's so packed with crap. Sorry, excuse my language." (Group 3, Respondent 5).

4.4.5. Summary of discussion groups

Although the participants in the discussion groups were recruited as they were over the age of 65, many identified as belonging to some of the clinically vulnerable groups such as having diabetes, using a PPI or having rheumatoid arthritis. During the discussions, pregnant individuals were particularly identified as being clinically vulnerable to foodborne illness. Participants were generally unaware that they may be at an increased risk of foodborne illness due to age or underlying conditions, nevertheless, many were able to comprehend immune system modifications when given a rationale. Discussions indicated the need to enable people to self-identify if they are at increased risk of foodborne illness. Some people found it easier to accept vulnerability resulting from a medical conditions or medications, rather than age alone. Denial about ageing was also discussed.

Many trusted sources of information were discussed, there are many opportunities for Food Standards Scotland to collaborate with NHS health professionals and other organisations and charities that provide advice, support or services for specific clinically vulnerable groups.

Although these discussions provide insight into potential approaches to communicating who are the clinically vulnerable groups, there is also a need to obtain a deeper understanding regarding the factors that may result in people disregarding food safety messaging. Consequently, exploration of the SEFARI fellowship group discussions with people over the age of 65 and those who support them (n=130) will develop a Holistic Food Safety Behavioural Framework based on potential determinants of food safety risks, behaviours and vulnerabilities, (namely biological, physical, psychological, economic, and social dimensions) along with the constructs of the Health Belief Model (which considers perceived susceptibility, perceived severity, perceived benefits, perceived barriers, cues to action, and self-efficacy) (Rosenstock, 1974). This will allow an in-depth exploration of the factors that influence food safety behaviours and obtain a better understanding of why food safety messaging may be discarded to refine food safety communication strategies.

5. Discussion

To undertake a comprehensive review of the current definition of "clinically vulnerable groups", this research has consolidated Scottish prevalence data to determine who are the clinically vulnerable groups in Scotland, with regards to foodborne illness. It was determined that despite people over the age of 65 years making up 20% of the population in Scotland, 68% of listeriosis, 31% of campylobacteriosis and 63% of norovirus cases were among older adults. Likewise, 5% of the population consist of children under the age of five, however 14 – 20% of Salmonella, STEC and norovirus cases were among this age group. Data were only available regarding listeriosis for pregnancy, cancer and rheumatoid arthritis associated cases. Additionally, interesting findings were consolidated regarding prevalence of foodborne illness among people prescribed proton pump inhibitors, medication for diabetes, or antibiotics. To enable a better understanding of foodborne illness among these groups, advancements in surveillance methods would be required.

By integrating the narrative review detailing the physiological reasoning of susceptibility with the systematic review of foodborne illness prevalence, we have provided an in-depth and comprehensive understanding of foodborne illness among clinically vulnerable groups in developed countries. In line with the data captured from Scotland, prevalence of pregnancy-associated foodborne illness, other than listeriosis, are seldom captured. Literature suggests that the immune system of a pregnant individual modulates to accommodate foetal development, and that immune response is pathogen specific, thus, the focus of capturing data on intracellular pathogens that can cross the placental barrier such as *L. monocytogenes* is justified.

At either end of the ageing scale groups are prone to foodborne illness. For example, children have heightened susceptibility to foodborne illness due to limited immune system development, whilst among older adults, ageing leads to progressive deterioration of the immune system. However, among older adults, frequent presence of chronic conditions and the medications used to treat such conditions add additional layers of susceptibility. Data regarding prevalence of all five pathogens of interest were obtained for children and older adults. Differences in prevalence of various foodborne illnesses among children were observed in the reviewed studies.

With regards to older adults, in Scotland, 68% of listeriosis cases were among people aged ≥65 years and 65 – 76% in reviewed studies. Prevalence of other foodborne illnesses among older adults were found to be higher in Scotland than in similar countries. For example, prevalence of campylobacteriosis was 23% in Scotland compared to 3 – 14% in similar countries. Likewise, in Scotland, 60% of norovirus infections were among older adults, while in similar countries prevalence ranged between 14 – 22%. Although trends in ageing across the UK nations suggest that Scotland has a higher median age (42 years) and a higher percentage of people aged ≥65 years (19.1%) than England (40 years, 18.4%) and Northern Ireland (38.9 years, 16.6%) (Office for National Statistics, 2020); it is reported that 21.3% of the

population of the European Union was aged ≥65 years (Eurostat, 2024). Italy and Portugal were the European countries with the largest percentage of older adults, with 24% of the total population aged ≥65 years. Bulgaria, Czechia, and Finland had 23%. Ireland, Iceland, Luxembourg, and Türkiye had the lowest percentage, with 15.2 – 9.9% of their population in the ≥65 years age category (Eurostat, 2024). In the US, 16.8% of the population are aged ≥65 years (United States Census Bureau, 2023), therefore high prevalence of Campylobacter and norovirus are unlikely to be as a direct result of variations in proportions of people aged ≥65 years in Scotland. It is not known if this is due to differences in surveillance systems, consequently this warrants further exploration in future.

In this study, we have identified several clinically vulnerable groups and documented the physiological reasons that increase their susceptibility to foodborne illness. Although prevalence studies provided evidence of *L. monocytogenes* associated with such groups, there is a dearth of data detailing prevalence of Salmonella, *E. coli,* Campylobacter, and norovirus among several clinically vulnerable groups, other than children and older adults.

Therefore, based on available data, we identified groups that should be acknowledged as being clinically vulnerable to foodborne illness, including PPI users, people with diabetes, rheumatoid arthritis, cancer, and IBD. Although the prevalence of some of these conditions may be relatively low, these groups are disproportionately affected by foodborne illness particularly listeriosis.

The review of definitions used by other food safety organisations worldwide indicates that the YOPI (Young, Old, Pregnant, Immunocompromised) grouping is most frequently referred to. While some definitions acknowledge people with cancer as being susceptible, the groups disproportionately affected by listeriosis, such as PPI users, people with diabetes, people with rheumatoid arthritis, people with cancer, and people with IBD, are seldom mentioned in these definitions.

6. Recommendations

The consolidated findings have been scrutinised during three expert panel consultations to consider clinically vulnerable groups; these discussions helped inform the recommendations arising from this report. Therefore, the key recommendations acknowledge that:

- Ageing population needs to be broken down into categories according to conditions or medications. For example, GI conditions that require medications, chronic inflammatory diseases such as diabetes, cancers, and others.
- We defined susceptibility to foodborne illness among PPI users and provided a summary of data that demonstrated high prevalence of foodborne illness among PPI users. Furthermore, we determined that PPI users are neglected as a clinically vulnerable group in global definitions. Consequently, due to this compelling evidence, we recommend that PPI users should be addressed as a vulnerable population due to the demonstrated risk of foodborne illness among this group.
- From our research, most prevalence data linked to vulnerable populations comes from Listeria surveillance studies. Therefore, there is a lack of surveillance data to explore the merit of having pathogen-based definitions of clinically vulnerable groups, other than for Listeria. Future surveillance needs to capture data according to the clinically vulnerable groups to understand comorbidities for foodborne illness.
- More information needs to be captured detailing underlying conditions in patients with foodborne illnesses. Furthermore, to enable understanding of multimorbidity contributions to the risk of foodborne illnesses, it is necessary to enhance coding protocols in healthcare.
- Age cut-offs for young children and older adults are not solely based on immunological vulnerabilities, rather they reflect the period during the lifespan when an individual is more likely to develop certain comorbidities that would contribute to their susceptibility to foodborne illness. Due to high variability in individuals, and different perceptions among consumers, there is a need for further research to determine how cut-off age can be used most efficiently. Discussions with people aged ≥65 years established that grouped definitions (e.g. older adults) may result in consumer food safety messaging being ignored as the intended audience may not perceive that it is intended for them.
- Targeted communication is required for each clinically vulnerable group. Different levels of messaging complexity are required for consumers and healthcare providers. Research is required to explore healthcare professional perceptions regarding their role of communicating food safety to clinically vulnerable groups.
- While it was out of the scope of this review, we acknowledge that socio-demographic and behavioural factors also contribute to the risk of foodborne illnesses, therefore we recommend that further research is required to explore

their contributions to susceptibility among clinically vulnerable groups. This may support further targeted communication approaches.

- It is acknowledged that public health agencies in different countries post annual foodborne disease reports on their websites and may not necessarily publish or index in electronic databases, therefore such reports require researchers to access these individually and require prior knowledge of their availability and location as such report are omitted when undertaking a systematic search. Therefore, for maximum utility, we recommend that public health agencies or food safety organisations attempt to peer-review and publish their annual reports on foodborne disease prevalence.

6.1. Future research recommendations

As a result of this work, we have identified several knowledge gaps that warrant future research. Specifically, consumer perceptions regarding food safety messaging for clinically vulnerable groups remain poorly understood. To facilitate the development of effective consumer food safety communication, research should focus on elucidating their awareness of food safety risks, preferred level of detail, acceptability of content and layout of materials. Our research highlights that PPI users stand out as a group that has been neglected in food safety communication. Prioritising consumer food safety research on this group is recommended. Additionally, a better understanding of the ageing population is necessary for targeted food safety messaging. The ageing population comprises of multiple clinically vulnerable groups, based on multiple generations and various co-morbidities, this also includes numerous behavioural and lifestyle factors. Further research should aim to discern the most appropriate categorisation for this diverse adult population, focusing on the consumer preference and perceptions.

Furthermore, healthcare professionals and social care providers play a critical role in providing trusted information and support to patients. However, there is limited understanding of their perceptions, attitudes, and preparedness to offer food safety advice to vulnerable patients. To effectively leverage opportunities in healthcare for improving food safety and wellness among clinically vulnerable groups, more evidence is needed regarding existing food safety training and education mechanisms for healthcare professionals. Such data will enable the development of tailored communication strategies for healthcare professionals and care providers.

7. Conclusions

This comprehensive review was undertaken on behalf of Food Standards Scotland to characterise clinically vulnerable groups in Scotland with respect to foodborne illness. By integrating physiological explanations with prevalence data, the study has successfully provided a comprehensive understanding of foodborne illness susceptibility among clinically vulnerable groups.

It is evident from our research that there is no specific age at which susceptibility increases. Therefore, future definitions, research and education should not solely mention chronological age or a generic terminology for people with compromised immune function, but instead should refer to specific underlying conditions and medication use as identified in this report to ensure that information given to clinically vulnerable groups is comprehensive and relatable.

Integrating the recommendations made in this report into future communication strategies will improve awareness among clinically vulnerable groups in Scotland of their susceptibility to better protect them from foodborne illnesses in the future.

8. Limitations

It must be acknowledged that only published studies detailing laboratory confirmed cases are included in the reviewed data. It is suggested that actual incidence is likely to be higher due to under reporting.

This report only includes annual reports for Scotland and the UK, annual reports from other countries were not included. We acknowledge that including national-level reports alongside peer-reviewed publications, is valuable and should be considered for future iterations of such analyses. Nevertheless, this report successfully identifies the clinically vulnerable groups in Scotland and provides a comparison with other countries.

Although including the annual reports from other countries may allow for more precise comparison between pathogens and years during which the infections took place, they would not add any addition detail regarding the clinically vulnerable groups. Prevalence data associated with specific behaviours, socio-economic and lifestyle factors were beyond the scope of this study and are considered as part of the SEFARI Fellowship with Food Standards Scotland (SEFARI, 2023).

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11. Appendices

Appendix 1. Bibliographic databases search strategy.

Web of Science Core Collection (Clarivate): TS=Topic search

(TS=("vulnerable populations" OR "vulnerable people" OR "clinically vulnerable groups" OR underserved OR disadvantaged OR marginalized OR minorit* OR underprivileged OR at-risk OR poverty OR poor OR "social status" OR "social class" OR "low-income population" OR inequality* OR "socioeconomic status" OR "socioeconomic factor*" OR deprivation)

OR TS=(elderly OR geriatric* OR senior OR gerontolog* OR (((age OR aged) NEAR/3 (over OR older) NEAR/2 (60 or 65 or 70 or 75 or 80 or 85 or 90 or 95))) OR (older NEAR/1 (adult$ OR m?n OR wom?n OR person$ OR people)) OR "middle age" OR (((Age OR aged) NEAR/3 (under OR younger) NEAR/2 (5 OR 4 OR 3 OR 2 OR 1))) OR kindergarten OR "child day care" OR "child care" OR preschool OR "nursery school" OR infancy OR newborn*OR new-born OR infan* OR neonate* OR baby OR babies OR toddler* OR preschool* OR child* OR young* OR youth*)

OR TS=(diabet* OR "liver disease*" OR cirrhosis OR "kidney disease*" OR alcohol* OR hiv OR "human immunodeficiency virus" OR aids OR "autoimmune diseases" OR cancer* OR transplant* OR stress OR "gastrointestinal disease*" OR "crohn disease" OR "crohn's disease" OR hyperlipoproteinemia OR "bowel disease" OR "bowel syndrome" OR "bowel disorder" OR malnutrition OR "nutritional deficienc*" OR undernutrition OR malnourish* OR "food insecurity" OR pregnancy OR smoking OR vaping OR "protein-pump inhibitor*" OR ppi OR "gastro-oesophageal reflux" OR immunosuppress* OR immunocompromised OR hypogammaglobulinemia OR immunodeficient* OR immunosuppressant* OR neoplasm OR ulcer* OR coeliac OR gastritis OR arthritis OR "immunologic factors"))

AND (TS=(food OR foodborn* OR food-born* OR "foodborn* disease*" OR "food contamination*" OR "food poisoning*")) AND (TS=(campylobacter* OR "campylobacter infection*" OR salmonell* OR "salmonella infections*" OR escherichia OR "e. coli" OR stec OR o157 OR non-o157 OR "escherichia coli infections" OR listeria OR listerios* OR norovirus OR caliciviridae OR "norwalk virus" OR "norovirus infections" OR toxoplasm*))

AND (TS=(australia OR austria OR "baltic states" OR belgium OR canada OR "czech republic" OR denmark OR estonia OR finland OR france OR germany OR greece OR hungary OR iceland OR ireland OR italy OR latvia OR luxembourg OR netherlands OR "new zealand" OR norway OR poland OR portugal OR scandinavia OR "slovak republic" OR slovenia OR spain OR sweden OR switzerland OR "united states" OR "western europe" OR "european union" OR "united kingdom" OR britain OR england OR scotland OR wales))

AND (TS=(incidence* OR prevalence OR outbreak* OR endemic* OR rate* OR occurrence* OR epidemic* OR epidemiolog*OR frequenc* OR case* OR infection* OR hospitali*))

Publication type=Journal Article

CABI: CAB Abstracts and Global Health (Clarivate): TS=Topic search, DE=Descriptors search

(TS=("vulnerable populations" OR "vulnerable people" OR "clinically vulnerable groups" OR underserved OR disadvantaged OR marginalized OR minorit* OR underprivileged OR at-risk OR poverty OR poor OR "social status" OR "social class" OR "low-income population" OR inequality* OR "socioeconomic status" OR "socioeconomic factor*" OR deprivation)

OR TS=(elderly OR geriatric* OR senior OR gerontolog* OR (((age OR aged) NEAR/3 (over OR older) NEAR/2 (60 or 65 or 70 or 75 or 80 or 85 or 90 or 95))) OR (older NEAR/1 (adult$ OR m?n OR wom?n OR person$ OR people)) OR "middle age" OR (((Age OR aged) NEAR/3 (under OR younger) NEAR/2 (5 OR 4 OR 3 OR 2 OR 1))) OR kindergarten OR "child day care" OR "child care" OR preschool OR "nursery school" OR infancy OR newborn*OR new-born OR infan* OR neonate* OR baby OR babies OR toddler* OR preschool* OR child* OR young* OR youth*)

OR TS=(diabet* OR "liver disease*" OR cirrhosis OR "kidney disease*" OR alcohol* OR hiv OR "human immunodeficiency virus" OR aids OR "autoimmune diseases" OR cancer* OR transplant* OR

stress OR "gastrointestinal disease*" OR "crohn disease" OR "crohn's disease" OR hyperlipoproteinemia OR "bowel disease" OR "bowel syndrome" OR "bowel disorder" OR malnutrition OR "nutritional deficienc*" OR undernutrition OR malnourish* OR "food insecurity" OR pregnancy OR smoking OR vaping OR "protein-pump inhibitor*" OR ppi OR "gastro-oesophageal reflux" OR immunosuppress* OR immunocompromised OR hypogammaglobulinemia OR immunodeficient* OR immunosuppressant* OR neoplasm OR ulcer* OR coeliac OR gastritis OR arthritis OR "immunologic factors"))

AND (TS=(food OR foodborn* OR food-born* OR "foodborn* disease*" OR "food contamination*" OR "food poisoning*")) AND (TS=(campylobacter* OR "campylobacter infection*" OR salmonell* OR "salmonella infections*" OR escherichia OR "e. coli" OR stec OR o157 OR non-o157 OR "escherichia coli infections" OR listeria OR listerios* OR norovirus OR caliciviridae OR "norwalk virus" OR "norovirus infections" OR toxoplasm*))

AND (TS=(incidence* OR prevalence OR outbreak* OR endemic* OR rate* OR occurrence* OR epidemic* OR epidemiolog*OR frequenc* OR case* OR infection* OR hospitali*))

AND (TS=(australia OR austria OR "baltic states" OR belgium OR canada OR "czech republic" OR denmark OR estonia OR finland OR france OR germany OR greece OR hungary OR iceland OR ireland OR italy OR latvia OR luxembourg OR netherlands OR "new zealand" OR norway OR poland OR portugal OR scandinavia OR "slovak republic" OR slovenia OR spain OR sweden OR switzerland OR "united states" OR "western europe" OR "european union" OR "united kingdom" OR britain OR england OR scotland OR wales))

AND (DE=(man))

Document type=Journal Article

MEDLINE (Clarivate): TS=Topic search, MH=MeSH Heading search

(TS=("vulnerable populations" OR "vulnerable people" OR "clinically vulnerable groups" OR underserved OR disadvantaged OR marginalized OR minorit* OR underprivileged OR at-risk OR poverty OR poor OR "social status" OR "social class" OR "low-income population" OR inequality* OR "socioeconomic status" OR "socioeconomic factor*" OR deprivation)

OR TS=(elderly OR geriatric* OR senior OR gerontolog* OR (((age OR aged) NEAR/3 (over OR older) NEAR/2 (60 or 65 or 70 or 75 or 80 or 85 or 90 or 95))) OR (older NEAR/1 (adult$ OR m?n OR wom?n OR person$ OR people)) OR "middle age" OR (((Age OR aged) NEAR/3 (under OR younger) NEAR/2 (5 OR 4 OR 3 OR 2 OR 1))) OR kindergarten OR "child day care" OR "child care" OR preschool OR "nursery school" OR infancy OR newborn*OR new-born OR infan* OR neonate* OR baby OR babies OR toddler* OR preschool* OR child* OR young* OR youth*)

OR TS=(diabet* OR "liver disease*" OR cirrhosis OR "kidney disease*" OR alcohol* OR hiv OR "human immunodeficiency virus" OR aids OR "autoimmune diseases" OR cancer* OR transplant* OR stress OR "gastrointestinal disease*" OR "crohn disease" OR "crohn's disease" OR hyperlipoproteinemia OR "bowel disease" OR "bowel syndrome" OR "bowel disorder" OR malnutrition OR "nutritional deficienc*" OR undernutrition OR malnourish* OR "food insecurity" OR pregnancy OR smoking OR vaping OR "protein-pump inhibitor*" OR ppi OR "gastro-oesophageal reflux" OR immunosuppress* OR immunocompromised OR hypogammaglobulinemia OR immunodeficient* OR immunosuppressant* OR neoplasm OR ulcer* OR coeliac OR gastritis OR arthritis OR "immunologic factors"))

AND (TS=(food OR foodborn* OR food-born* OR "foodborn* disease*" OR "food contamination*" OR "food poisoning*")) AND (TS=(campylobacter* OR "campylobacter infection*" OR salmonell* OR "salmonella infections*" OR escherichia OR "e. coli" OR stec OR o157 OR non-o157 OR "escherichia coli infections" OR listeria OR listerios* OR norovirus OR caliciviridae OR "norwalk virus" OR "norovirus infections" OR toxoplasm*))

AND (TS=(incidence* OR prevalence OR outbreak* OR endemic* OR rate* OR occurrence* OR epidemic* OR epidemiolog*OR frequenc* OR case* OR infection* OR hospitali*))

AND (TS=(australia OR austria OR “baltic states” OR belgium OR canada OR “czech republic” OR denmark OR estonia OR finland OR france OR germany OR greece OR hungary OR iceland OR ireland OR italy OR latvia OR luxembourg OR netherlands OR “new zealand” OR norway OR poland OR portugal OR scandinavia OR “slovak republic” OR slovenia OR spain OR sweden OR switzerland OR “united states” OR “western europe” OR “european union” OR “united kingdom” OR britain OR england OR scotland OR wales))

AND (MH=(humans))

Publication type=Journal Article

Appendix 2. Grey literature search strategy.

UK Health Security Agency (UKHSA)

site: gov.uk “health security agency” AND campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: gov.uk “health security agency” AND salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: gov.uk “health security agency” AND (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: gov.uk “health security agency” AND listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: gov.uk “health security agency” AND norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: gov.uk “health security agency” AND (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Food Standards Agency (FSA)

site: food.gov.uk campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: food.gov.uk salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: food.gov.uk (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: food.gov.uk listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: food.gov.uk norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: food.gov.uk (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Food Standards Scotland (FSS)

site: foodstandards.gov.scot campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.scot salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.scot (Escherichia OR e.coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.scot listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.scot norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.scot (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Advisory Committee on the Microbiological Safety of Food

site: acmsf.food.gov.uk campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: acmsf.food.gov.uk salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: acmsf.food.gov.uk (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: acmsf.food.gov.uk listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: acmsf.food.gov.uk norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: acmsf.food.gov.uk (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Department for Environment, Food and Rural Affairs (DEFRA)

site: defra.gov.uk campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: defra.gov.uk salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: defra.gov.uk (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: defra.gov.uk listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: defra.gov.uk norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

British Retail Consortium (BRC)

site: brc.org.uk campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: brc.org.uk salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: brc.org.uk (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: brc.org.uk listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: brc.org.uk norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: brc.org.uk (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Food Safety Authority of Ireland (FSAI)

site: fsai.ie campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsai.ie salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsai.ie (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsai.ie listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsai.ie norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsai.ie (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Safefood

site: safefood.net campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: safefood.net salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: safefood.net (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: safefood.net listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: safefood.net norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: safefood.net (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Food Standards Australia New Zealand (FSANZ)

site: foodstandards.gov.au campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.au salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.au (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.au listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.au norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodstandards.gov.au (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Department of Agriculture, Fisheries and Forestry (DAFF)

site: agriculture.gov.au campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.gov.au salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.gov.au (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.gov.au listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.gov.au norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.gov.au (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

New South Wales Food Authority (NSW Food Authority)

site: foodauthority.nsw.gov.au campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodauthority.nsw.gov.au salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodauthority.nsw.gov.au (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodauthority.nsw.gov.au listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodauthority.nsw.gov.au norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodauthority.nsw.gov.au (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

New South Wales Department for Primary Industries

site: dpi.nsw.gov.au campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: dpi.nsw.gov.au salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: dpi.nsw.gov.au (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: dpi.nsw.gov.au listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: dpi.nsw.gov.au norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: dpi.nsw.gov.au (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Public Health Agency of Canada (PHAC)

site: www.canada.ca/en/public-health campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/public-health salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/public-health (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/public-health listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/public-health norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/public-health (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Health Canada

site: www.canada.ca/en/health-canada campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/health-canada salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/health-canada (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/health-canada listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/health-canada norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.canada.ca/en/health-canada (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Canadian Food Inspection Agency (CFIA)

site: inspection.canada.ca/eng campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: inspection.canada.ca/eng salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: inspection.canada.ca/eng (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: inspection.canada.ca/eng listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: inspection.canada.ca/eng norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: inspection.canada.ca/eng (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Agriculture and Agri-Food Canada (AAFC)

site: agriculture.canada.ca/en campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.canada.ca/en salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.canada.ca/en (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.canada.ca/en listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.canada.ca/en norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: agriculture.canada.ca/en (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Health Products and Food Branch, Health Canada (HPFB)

site: canada.ca “Health Products and Food Branch” AND campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: canada.ca “Health Products and Food Branch” salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: canada.ca “Health Products and Food Branch” AND (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: canada.ca “Health Products and Food Branch” AND listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: canada.ca “Health Products and Food Branch” AND norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: canada.ca “Health Products and Food Branch” AND (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Center for Food Safety and Applied Nutrition (CFSAN), U.S. Food and Drug Administration

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.fda.gov “Center for Food Safety and Applied Nutrition” AND (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Centers for Disease Control and Prevention (CDC)

site: www.cdc.gov campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.cdc.gov salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.cdc.gov (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.cdc.gov listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.cdc.gov norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.cdc.gov (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

U.S. Food and Drug Administration (FDA)

site: fda.gov campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fda.gov salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fda.gov (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fda.gov listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fda.gov norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fda.gov (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Food Service and Inspection Service (FSIS), U.S. Department of Agriculture

site: fsis.usda.gov campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsis.usda.gov salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsis.usda.gov (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsis.usda.gov listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsis.usda.gov norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fsis.usda.gov (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

International Food Protection Training Institute (IFPTI)

site: ifpti.org campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ifpti.org salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ifpti.org (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ifpti.org listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ifpti.org norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ifpti.org (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

U.S. Department of Agriculture

site: usda.gov campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: usda.gov salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: usda.gov (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: usda.gov listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: usda.gov norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: usda.gov (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

The Partnership for Food Safety Education

site: fightbac.org campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fightbac.org salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fightbac.org (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fightbac.org listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fightbac.org norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fightbac.org (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

International Food Information Council (IFIC)

site: ific.org campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ific.org salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ific.org (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ific.org listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ific.org norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: ific.org (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

International Association for Food Protection (IAFP)

site: foodprotection.org campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodprotection.org salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodprotection.org (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodprotection.org listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodprotection.org norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: foodprotection.org (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

The International Commission on Microbiological Specifications for Foods (ICMSF)

site: icmsf.org campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: icmsf.org salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: icmsf.org (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: icmsf.org listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: icmsf.org norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: icmsf.org (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

World Health Organization (WHO)

site: www.who.int campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.who.int salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.who.int (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.who.int listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.who.int norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: www.who.int (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

FAO/WHO International Food Safety Authorities Network (INFOSAN)

Infosan AND campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Infosan AND salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Infosan AND (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Infosan AND listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Infosan AND norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Infosan AND (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Global Food Safety Initiative (GFSI)

site: mygfsi.com campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: mygfsi.com salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: mygfsi.com (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: mygfsi.com listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: mygfsi.com norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: mygfsi.com (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Joint FAO/WHO Expert Committee on Food Additives (JECFA)

site: fao.org/food-safety/resources/publications/en/ campylobacter AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fao.org/food-safety/resources/publications/en/ salmonella AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fao.org/food-safety/resources/publications/en/ (Escherichia OR e. coli) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fao.org/food-safety/resources/publications/en/ listeria AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fao.org/food-safety/resources/publications/en/ norovirus AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

site: fao.org/food-safety/resources/publications/en/ (campylobacter OR salmonella OR escherichia OR e. coli OR listeria OR norovirus) AND (risk OR vulnerable OR susceptible) AND (foodborne OR "food poisoning" OR "food contamination" OR “food safety”)

Appendix 3. Grey literature data capture tool.

Default Question Block

Coder ID

- ○ EE
- ○ FD
- ○ SI
- ○ AH
- ○ AD

Document ID number e.g. CDC_001, FSAI_001

Details of organisation

Country

Organisation

Does the document come from multiple organisations?

- ○ Yes (name below)
- ○ No

Document name

Document URL

Name of author(s) or Anonymous

Year of publication / last update

Source type

- [ ] General information (not specified)
- [ ] Consumer advice/information (e.g. website/PDF)
- [ ] Guidance/information for healthcare (professionals/institutions)
- [ ] Guidance/information for industry (food manufacturing and food service)
- [ ] Report (Public health reports/Risk Assessment)
- [ ] Other (specify)

Definition included (copy and paste)

Does this document provide context why people are vulnerable/at-risk?

- ○ Yes
- ○ Only states 'because of weakened immune system'
- ○ No

If yes, copy and paste the rationale:

Vulnerable groups included

	General/non-specific foodborne pathogens	Listeria	Campylobacter	*E. coli*/ STEC	Salmonella	Norovirus	Other pathogen
General weakened immune system (non specific)	☐	☐	☐	☐	☐	☐	☐
Cancer patients under going immunosuppressive treatment	☐	☐	☐	☐	☐	☐	☐
Cancer patients (other therapies, e.g. radiation)	☐	☐	☐	☐	☐	☐	☐
Cancer patients (unspecified)	☐	☐	☐	☐	☐	☐	☐
Transplant patients	☐	☐	☐	☐	☐	☐	☐
HIV/AIDS	☐	☐	☐	☐	☐	☐	☐

	General/non-specific foodborne pathogens	Listeria	Campylobacter	*E. coli*/ STEC	Salmonella	Norovirus	Other pathogen
IBD/IBS/Crohns patients	☐	☐	☐	☐	☐	☐	☐
People with Multiple Sclerosis	☐	☐	☐	☐	☐	☐	☐
People with Rheumatoid Arthritis	☐	☐	☐	☐	☐	☐	☐
People with diabetes	☐	☐	☐	☐	☐	☐	☐
Elderly	☐	☐	☐	☐	☐	☐	☐
Pregnant women/unborn infants	☐	☐	☐	☐	☐	☐	☐

	General/non-specific foodborne pathogens	Listeria	Campylobacter	*E. coli*/ STEC	Salmonella	Norovirus	Other pathogen
Neonates / newly delivered infants	☐	☐	☐	☐	☐	☐	☐
Children (underdeveloped immune system)	☐	☐	☐	☐	☐	☐	☐
People prescribed proton-pump inhibitor (PPI) for gastro issues	☐	☐	☐	☐	☐	☐	☐
Eating disorders (malnourished)	☐	☐	☐	☐	☐	☐	☐
Obesity (and metabolic syndromes)	☐	☐	☐	☐	☐	☐	☐
Alcoholics (including those with alcoholic liver disease)	☐	☐	☐	☐	☐	☐	☐

	General/non-specific foodborne pathogens	Listeria	Campylobacter	*E. coli*/ STEC	Salmonella	Norovirus	Other pathogen
Gender - Female	☐	☐	☐	☐	☐	☐	☐

	General/non-specific foodborne pathogens	Listeria	Campylobacter	*E. coli*/ STEC	Salmonella	Norovirus	Other pathogen
Gender - Male	☐	☐	☐	☐	☐	☐	☐
Other autoimmune diseases (specify)	☐	☐	☐	☐	☐	☐	☐
Other chronic conditions (cardiovascular, kidney, liver, gastrointestinal, etc.)	☐	☐	☐	☐	☐	☐	☐
Other medication related vulnerabilities (specify name/type of medication, e.g. Antibiotic use)	☐	☐	☐	☐	☐	☐	☐
Other (please state)	☐	☐	☐	☐	☐	☐	☐

Specify pathogen

Is a specific age given for elderly/older adults?

- ○ No, refers to elderly/older adults old
- ○ Yes, specify age

Is a specific age given for children?

- ○ No, refers to children only
- ○ Yes, specify age

Is different guidance given to different vulnerable groups

- ○ Yes
- ○ No
- ○ N/A

Is the document specific to one population(s)?

- ○ No
- ○ Yes (specify)

Is the document specific to a specific food(s)?

- ○ No
- ○ Yes (specify) _____

Reference to source of information

- ☐ Refers to previous research (with references)
- ☐ Refers to previous research (without references)
- ☐ Refers to other source of information (with link)
- ☐ Refers to other source of information (without link)
- ☐ Refers to a generic/non-specific source (e.g. organisation home page)
- ☐ No reference or source of information

Details of research referred to:

Details of other source referred to:

Has a PDF of this document been saved?

- ○ Yes
- ○ No

Appendix 4. Expert panel participants.

Name	Position	Organisation	Country
Alicyn Dickman	Research Dietitian	The Ohio State University	United States
Andrea Nesbitt	Acting Manager	Public Health Agency of Canada	Canada
Angela Webb	Foodborne illness Policy	Food Standards Agency	United Kingdom
Cecile Punzalan	Medical Officer	FDA CFSAN	United States
Delyth James	Professor of Health Psychology in Pharmacy Practice	Cardiff Metropolitan University	United Kingdom
Elizabeth Redmond	Professor of Food Safety, Health and Behaviour	ZERO2FIVE Food Industry Centre	United Kingdom
Ian Young	Associate Professor	Toronto Metropolitan University	Canada
Jeff Farber	Adjunct Professor	University of Guelph	Canada
Jeffrey T. LeJeune	Food Safety Officer	Food and Agriculture Organization of the United Nations	Italy
Jennifer Quinlan	Professor and Executive Director of the Integrated Food Security Research Center	Prairie View A&M University	United States
Kate Thomas	Manager	Public Health Agency of Canada	Canada
Nicol Janecko	Bioscience Career-track group leader	Quadram Institute	United Kingdom
Philip Calder	Professor of Nutritional Immunology	University of Southampton	United Kingdom
Roberto Vivancos	Consultant Epidemiologist	UK Health Security Agency	United Kingdom
Rohini Joanna Manuel	Consultant Microbiologist	UK Health Security Agency	United Kingdom
Sarah O'Brien	Professor of Translational Agritechnology	Newcastle University	United Kingdom
Shauna C. Henley	Senior Family & Consumer Sciences Agent	University of Maryland Extension	United States
Stephen Parker	Director Foodborne illness and AMR Surveillance	Public Health Agency of Canada	Canada
Wayne Anderson	Director Food Science and Standards	Food Safety Authority of Ireland	Ireland
Wieke van der Vossen	Food safety expert and food database project leader	The Netherlands Nutrition Centre	Netherlands

Appendix 5. Table of notifiable disease-causing organism by countries.

Organism	US	UK	Canada	Australia	New Zealand	Europe	Scotland	Ireland
Bacillus cereus		✓					✓	✓
Campylobacter spp.	✓	✓	✓	✓	✓		✓	✓
Cronobacter spp.	✓							
***Clostridium botulinum* (botulism)**	✓	✓	✓	✓		✓		✓
Clostridium perfringens		✓					✓	✓
CJD			✓	✓	✓	✓		✓
Cryptosporidium spp.	✓	✓	✓	✓	✓	✓	✓	✓
Cyclospora spp.	✓		✓					
Giardia lamblia	✓	✓	✓		✓	✓	✓	✓
Hepatitis A	✓	✓	✓	✓	✓	✓	✓	✓
Hepatitis E		✓		✓			✓	✓
Listeria monocytogenes	✓	✓	✓	✓	✓	✓	✓	✓
Norovirus			✓				✓	✓
Salmonella spp.	✓	✓	✓	✓	✓	✓	✓	✓
Shiga toxin-producing *Escherichia coli*	✓	✓	✓	✓	✓	✓	✓	✓
Shigella spp.	✓	✓	✓	✓	✓	✓	✓	✓
Toxoplasma gondii						✓	✓	✓
Trichinella spp.	✓		✓					✓
Vibrio spp. (other than cholera)	✓							
Yersinia enterocolitica					✓	✓	✓	✓`

Appendix 6. Reference to specific clinically vulnerable groups according to pathogens in reviewed grey literature definitions (*n*=660).

Clinically vulnerable groups	*L. monocytogenes*		Campylobacter		*E. coli*		Salmonella		Norovirus		Non-specific foodborne pathogens	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Pregnant individuals/unborn infants	265	40%	20	3%	24	4%	40	6%	6	1%	94	14%
Older adults	242	37%	42	6%	71	11%	121	18%	16	2%	121	18%
General weakened immune system	226	34%	22	3%	44	7%	98	15%	17	3%	92	14%
Neonates / newly delivered infants	160	24%	10	2%	11	2%	41	6%	2	0%	23	3%
People with cancer (unspecified)	44	7%	5	1%	3	0%	13	2%	0	0%	14	2%
People with HIV/AIDS	41	6%	8	1%	1	0%	10	2%	0	0%	17	3%
People with diabetes	38	6%	4	1%	1	0%	6	1%	0	0%	20	3%
Other chronic conditions (e.g. cardiovascular, kidney, liver diseases)	35	5%	4	1%	1	0%	4	1%	0	0%	18	3%
Transplant recipients	32	5%	3	0%	2	0%	9	1%	0	0%	12	2%
Children	23	3%	40	6%	81	12%	105	16%	15	2%	119	18%
People with cancer (immunosuppressive treatment)	22	3%	4	1%	2	0%	1	0%	0	0%	10	2%
Other medication related vulnerabilities	19	3%	2	0%	0	0%	0	0%	0	0%	4	1%
People with alcohol use disorders (incl. alcoholic liver disease)	14	2%	0	0%	0	0%	0	0%	0	0%	4	1%
People with IBD/IBS/Crohn's	4	1%	0	0%	0	0%	0	0%	0	0%	2	0%
People with cancer (radiation therapy)	3	0%	0	0%	0	0%	0	0%	0	0%	4	1%
Other autoimmune diseases	1	0%	0	0%	0	0%	1	0%	0	0%	3	0%
People prescribed proton-pump inhibitors	1	0%	1	0%	0	0%	3	0%	0	0%	2	0%
People with Multiple Sclerosis	0	0%	0	0%	0	0%	0	0%	0	0%	1	0%
People with Rheumatoid Arthritis	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Eating disorders (malnourished)	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%

Suggested citation:

Evans, E.W. & Ilic, S. (2024) Examining Vulnerability to Foodborne Illness: A Comprehensive Review of “Clinically Vulnerable Groups”. Research undertaken on behalf of Food Standards Scotland.

Food Industry Centre
Cardiff Metropolitan University
ZERO2FIVE Food & Drink Research Unit
Uned Ymchwil Bwyd a Diod
Canolfan Diwydiant Bwyd
Prifysgol Metropolitan Caerdydd

Food Standards Scotland
For safe food and healthy eating

The Ohio State University