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Characteristics of Foodborne Disease Outbreak Investigations in Colorado with Known Food Vehicle, 2009 – 2019

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Abstract

Characteristics of Foodborne Disease Outbreak Investigations in Colorado with Known Food Vehicle, 2009 – 2019

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Background: Foodborne illnesses are an important public health problem in the United States. Investigation of foodborne disease outbreaks can lead to the identification of the causal etiology and food vehicle, which is important for informing food safety efforts. Characteristics of foodborne disease outbreaks that identify a causal etiology are well established; however, characteristics of outbreaks that identify a food vehicle are less understood. This study examined the outbreak characteristics and investigation methods associated with foodborne disease outbreaks where a food vehicle was identified.

Methods: Data were available from the National Outbreak Reporting System (NORS) for single-state outbreaks occurring in Colorado from 2009 – 2019. Outbreak characteristics and investigation methods included: pathogen (norovirus, bacteria, bacterial toxin, other, unknown), case count (≥5 outbreak-associate cases), lead agency (state or a local health department), age group (≥25% pediatric cases or ≥25% senior cases), hospitalized cases (% of cases hospitalized), investigation method (routine investigation, analytic study, other method), exposure setting (retail food establishment, private residences, other, institution, unknown), human specimen collection (≥ 2 specimens collected), number of primary lab confirmed cases per outbreak, and geographical region (multi-county exposure and urban or rural county). Univariate analysis and multivariate analysis (logistic regression) was performed to determine characteristics significantly associated with identification of a food vehicle overall and stratified by detection method (complaint or pathogen-specific surveillance).

Results: A total of 451 foodborne outbreak occurred in Colorado from 2009 – 2019; 121 multi-state outbreaks were excluded. Of 330 single state outbreaks, 153 (46%) identified a food vehicle. When compared to outbreak than did not identify a food vehicle, outbreak that identified a food vehicle were significantly more likely to include: a bacterial pathogen (25% vs. 12%), a larger case count (61% vs. 57% with ≥ 5 cases), investigation led by the state health department (18% vs. 5%), more hospitalized cases per outbreak (average 8% vs. 4%), conducting an analytic study (51% vs. 38%), exposure in a private residence (23% vs. 12%), and a multi-county exposure (9% vs 2%)). For outbreaks detected by complaint, characteristics were: bacterial pathogen, more hospitalized cases, conducting an analytic study, and exposure in a private resident. In contrast, characteristics significantly associated with identifying a food vehicle for outbreaks detected by pathogen-specific surveillance were: a larger case count, and having the investigation led by the state agency. In the multivariable analysis, bacterial outbreaks (Odds Ratio [OR]: 3.44, 95% Confidence Interval [CI]: 0.1.52-7.78), whereas case count (OR: 1.02, 95% CI: 1.00-1.04), state as the lead agency (OR: 2.99; 95% CI: 1.14-7.89) and exposure in private residences (OR: 2.17, 95% CI: 1.09-4.30) were significantly associated with identification of a food vehicle.

Conclusions: The characteristics significantly associated with identifying a food vehicle in Colorado single-state foodborne included pathogen, case count, and lead agency, specifically, larger outbreaks, bacterial etiology, and outbreaks led by state health departments. These findings will be translated into recommendations and best practice guidelines for outbreak training opportunities geared towards public health agencies.

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CHAPTER 1

Burden of Foodborne Illnesses

Foodborne illnesses are an important public health problem in the United States. It is estimated that each year, 31 major pathogens acquired in the United States cause 9.4 million episodes of foodborne illness, resulting in 55,961 hospitalizations, and 1,351 deaths (Scallan, Hoekstra, et al., 2011). An additional 38.4 million domestically acquired foodborne illnesses, 71,878 hospitalizations, and 1,686 deaths are attributed to unspecified agents (Scallan, Griffin, et al., 2011), for a total of 47.8 million domestically acquired foodborne illnesses, 127,839 hospitalizations and 3,037 deaths. Over time, the incidence of foodborne illnesses has continued to rise or remained unchanged (Tack et al., 2020).

Foodborne illnesses are typically characterized by gastrointestinal symptoms, including but not limited to diarrhea and/or vomiting (Wikswo et al., 2021). Food may become contaminated by a variety of causative agents (i.e., bacterial, viral, toxin, parasite, and chemical) (Scallan, Hoekstra, et al., 2011) and contamination can occur at any point of food production, preparation, and processing (Tack et al., 2020). Foodborne illnesses are estimated to have a $15.5 billion (2013 dollars) impact yearly on the economy (Hoffmann et al., 2015), ranging from $4.8 billion to $36.6 billion (2013 dollars) (Hoffmann et al., 2015). Scharff (2012) determined the mean economic cost to be $1.3 million (U.S. dollars) for each *Listeria* case, $11,086 (U.S. dollars) for each *Salmonella* non-typhoidal case, and $10,048 (U.S. dollars) for STEC O157:H7 serotype case (the more prevalent STEC serotype). The majority of costs were associated with deaths; therefore, although mortality due to foodborne illnesses is low, economic burden is high. This highlights the importance of investigating foodborne illnesses and conducting outbreak activities, as these actions can lead to identification of food vehicles and linkage to causal pathogens (Hoffmann et al., 2015). Identification of a food vehicle can allow for its removal from the public and prevent subsequent illnesses and future outbreaks.

Foodborne Disease Outbreaks

A foodborne disease outbreak is defined as the occurrence of two or more cases of a similar illness resulting from ingestion of a common food (Dewey-Mattia et al., 2018). State, local, and territorial health departments track the occurrence of enteric disease outbreaks through surveillance and subsequent voluntary outbreak reporting to the Centers of Disease Control and Prevention (CDC) through the Foodborne Disease Outbreak Surveillance System (FDOSS). From 1998 – 2008, FDOSS used the Electronic Foodborne Outbreak Reporting System (EFORS) platform. In 2009, it was incorporated into the National Outbreak Reporting System (NORS), a web-based platform that includes all modes of transmission, such as foodborne (Dewey-Mattia et al., 2018). Outbreaks due to bacterial, parasitic, and viral pathogens, as well as chemicals and toxins, are reported to NORS (Dewey-Mattia et al., 2018). These etiologies can be classified as confirmed, suspected, or unknown, with the former two categories determined by specific criteria such as laboratory testing and clinical syndrome (Dewey-Mattia et al., 2018). Implicated food vehicles can be identified as the source through one or more of the following types of evidence: epidemiologic, laboratory, traceback, environmental assessment, or other data (Dewey-Mattia et al., 2018). When a source is not identified, the food vehicle is unknown (Dewey-Mattia et al., 2018).

In 2018, 1,052 foodborne disease outbreaks, resulting in 20,000 illnesses, 1,534 hospitalizations, and 21 deaths were reported by public health officials in the 50 states, Washington, D.C., and the 5 territories to the National Outbreak Reporting Systems (NORS) (CDC, 2019b); 2018 data is the most recently available data. In general, the incidence of foodborne disease outbreaks have remained relatively unchanged; although this may be attributable to improvements in disease surveillance and laboratory detection methods (Jones & Yackley, 2018) which have been successful at identifying emerging and novel vehicles of transmissions and pathogen strains (Kase et al., 2017). For example, the number of foodborne disease outbreaks in 2016 was 854 compare to 858 outbreaks in 2017 and 1,052 in 2018. Correspondingly, outbreak-associated illnesses, resulting hospitalizations and deaths all experienced a similar trend of remaining relatively unchanged or with a slight increase. There were 14,430 reported outbreak-associated illnesses in 2016, compared to 15,027 in 2018, to 20,000 in 2018; hospitalizations were 944 in 2016, compared to 979 in 2017, and 1,534 in 2020; lastly, outbreak-associated deaths were 28 in 2016 compared to 26 in 2017, and 21 in 2018 (CDC, 2019b).

Detecting Foodborne Disease Outbreaks

Foodborne disease outbreaks can be detected in two methods: pathogen-specific surveillance and complaint-based surveillance. Detection of foodborne disease outbreaks through pathogen-specific surveillance occurs through laboratory surveillance, which requires cases to be diagnosed and subsequently reported to public health agencies. This process starts when an ill individual seeks medical care and provides a specimen for laboratory testing. When clinical laboratories identify a causative pathogen, this result is then reported systematically to public health agencies and specimens forwarded to public health laboratories for confirmatory testing. Although pathogen-specific surveillance captures all laboratory-confirmed ill cases, ultimately some proportion of ill persons will not be reported because: (1) they do not seek medical care, (2) do not provide a stool specimen for testing, or (3) their laboratory results do not get reported to public health, representing underreporting (Scallan, Hoekstra, et al., 2011). Additionally, any break in the reporting process can also lead to the causative agent not being laboratory confirmed, representing underdiagnosis. Both underdiagnosis and underreporting of ill cases can result in delays in the identification of foodborne disease outbreaks.

Compounding this problem is the "lag window" or "reporting lag" associated with the time period before an ill case is even linked to an outbreak, which on average is 3 – 4 weeks and possibly longer for some pathogens (CDC DFWED, 2021). Although laboratory advancements such as molecular subtyping by pulsed-field gel electrophoresis (PFGE) and now, whole genome sequencing (WGS) are able to increase the likelihood of identifying an etiology and ill cases in outbreak scenarios, these methods further increase the reporting delay, with certain pathogens seemingly receiving priority for testing and a faster turnaround of reporting to investigators at the state health department (Hedberg et al., 2008). For example, Hedberg et al. (2008) discovered that for cases who were interviewed, the median interval from onset of symptoms to PFGE subtyping was 15 days for *E. coli* O157:H7, 18 days for *Salmonella* spp., and 21 days for *Shigella* spp. Timely reporting of foodborne illnesses is important for outbreak identification, therefore, pathogen-specific surveillance can be less agile at quickly detecting outbreaks among ill cases.

In contrast to pathogen-specific surveillance, consumer complaint-based surveillance is largely used at the local level and has the ability to detect foodborne outbreaks for a variety of pathogens, including those that are not mandatory reporting (Li et al., 2011). In a survey of local public health agencies in the U.S. by Li et al. (2011), approximately 81% of local agencies reported usage of complaint-based surveillance which was responsible for detection of 69% of foodborne outbreaks from the prior year. Li et al. (2011) concluded that a significant relationship existed between outbreak rates and complaint rates, indicating that agencies that received more complaints were also able to identify more outbreaks. Complaint-based systems are typically utilized by ill cases, and collect some portion of the following information: contact information of ill cases, information on the suspected establishment or causal product, onset and symptomology, food histories; healthcare providers also utilized these systems to report foodborne illnesses and potential outbreaks (Li et al., 2011).

Complaint-based surveillance is a more responsive and agile method of detecting outbreaks, and is associated with a shorter reporting lag as the reporting immediately triggers a response. Public health is also able to immediately identify other potential ill cases and initiate testing more rapidly which speeds up subsequent steps associated with confirmatory testing due to centralized testing at public health laboratories. Therefore, with the variable and potentially lengthy time requirements for foodborne disease outbreaks identification and the high proportion of outbreaks with no pathogen or food vehicle identified, understanding how differential detection methods, an outbreak characteristic, can increase the identification of both etiology and a food vehicle.

Public Health Impact of Foodborne Disease Outbreaks

Foodborne illnesses that occur outside of an outbreak setting rarely have information on food vehicles or exposure setting identified; on the other hand, conducting an outbreak investigation often leads to linking etiologies with specific foods, which allows for public health, regulatory agencies, and the food industry to investigate how contamination occurred and to take preventative actions (Dewey-Mattia et al., 2018). Outbreak data can also be useful in identifying emerging food safety issues and to assess whether existing programs are effective in prevention of illnesses (Dewey-Mattia et al., 2018). Outbreak investigations can lead to the identification of a causal etiology and analysis of epidemiologic data can help identify the food vehicle and/or confirm a suspect food vehicle in addition to analysis of historical data (Dewey-Mattia et al., 2018). Identification of both an etiology and food vehicle can increase food safety by: (1) identifying problems such as contaminated foods (2) initiating control activities such as removal of contaminated foods from the market and (3) improving practices such as implementing better preventative interventions (ODPHP, 2021). Outbreaks with known food vehicle may identify novel food-pathogen pairs, representing emerging atypical food vehicles (Dewey-Mattia et al., 2018). However, not all foodborne disease outbreaks have a food vehicle identified, representing a barrier to understanding food safety processes and how to implement food safety practices. In recent years, Jones & Yackley (2018) concluded that information about the vehicle of transmission in foodborne disease outbreaks has become increasingly available over time with variability in data quality; granular and well-categorized data were only reported in recent years.

With regards to common food vehicles, fish was the most frequently implicated single food vehicle in outbreaks but was associated with low number of ill cases due to how toxins contaminate food vehicles (Dewey-Mattia et al., 2018). Conversely, the most outbreak associated ill cases were attributable to *Salmonella* (turkey and chicken) due to mechanism of bacterial contamination, whereby large amounts of food product and potentially, across vast distribution chains, are contaminated (Dewey-Mattia et al., 2018). Therefore, bacterial pathogens are more likely to be linked with larger outbreaks and viewed as more severe, that is, those with greater rates of hospitalized ill cases, which may result in a higher likelihood of identifying the implicated food vehicle.

Solving Foodborne Outbreaks

Foodborne disease outbreaks that are detected by pathogen-specific surveillance are initially investigated as a cluster, that is a larger number of people than expected with the same illness in a given time period and area (CDC DFWED, 2018). Cluster cases are identified by molecular testing methods, which detect cases that are genetically identical or genetically very closely related but may be geographically dispersed. Previous research has examined characteristics of *Salmonella* and STEC clusters in Minnesota, that become confirmed outbreaks, that is when a common source of infection is identified. For *Salmonella*, Rounds et al. (2010) concluded that the proportion of clusters that were confirmed increased, as cluster size increased to 4, with no further increase for cluster size ≥ 5. Additionally, (Rounds et al., 2010) also concluded that the proportion of clusters that were confirmed also increased with cluster density, that is the number of days from receipt of the first isolate at the public health laboratory to receipt of the third isolate; cluster density ≤ 7 days, was more likely to be confirmed as an outbreak as well. For STEC clusters, Rounds et al. (2012) had similar conclusions, with a greater proportion of clusters confirmed when cluster size ≥ 3 and cluster density was < 8 days for receipt of the first isolate at the public health laboratory to receipt of the second isolate. These findings indicated that case count, specifically a minimum case count between 4 – 5 for *Salmonella* and a minimum of 3 for STEC was a characteristic of clusters that were confirmed as an outbreak. Furthermore, the density, that is how quickly the initial specimens were received at the lab, was also a characteristic of clusters that were confirmed as an outbreak. Therefore, case count and specimen collection were characteristics associated with identifying a common link between cases, that is, a cluster becoming an outbreak.

In an analysis of foodborne disease outbreaks reported to the Foodborne Disease Active Surveillance Network (FoodNet) surveillance areas from 2009 – 2015 in seven states, 49% of foodborne disease outbreaks had an unknown etiology and 58% had an unknown food vehicle (CDC, 2019a). The primary reason why an etiology was not identified was the lack of specimens collected (human or environmental). Furthermore, even if specimens were collected, during an outbreak, pathogen-specific testing may be requested of suspected pathogens rather than testing with a comprehensive panel of pathogens; this means that testing for the correct causal pathogen may be missed (Jones, Imhoff, et al., 2004). However, even in the absence of a confirmed etiology, useful information can still be gathered (i.e. suspect food vehicles potential environmental factors that led to the outbreak) (Jones, Imhoff, et al., 2004). Similarly, outbreaks where no food vehicle was identified can be due to lack of laboratory evidence or lack of epidemiologic evidence to implicate a food vehicle; for example, if there is not adequate epidemiologic information on how a food vehicle was implicated (Jones, Imhoff, et al., 2004).

Previous research identified characteristics of foodborne outbreaks where a food vehicle was identified that were significant: known pathogen, pathogen type, specimen collection, case count, lead agency, outbreak setting, and conduct of an analytic study. Jones, Bulens, et al. (2004) concluded that outbreaks with a pathogen identified had ≥ 1 stool specimen collected, which allowed for testing and identification of pathogen. Dewey-Mattia et al. (2018) discussed why bacterial outbreaks are the most common and also cause the highest case count during a single outbreak and the significance in identifying a food vehicle. Outbreaks that were larger, ≥ 10 were more likely to have both etiology (Jones, Imhoff, et al., 2004)and food vehicle identified (Dominguez et al., 2009). Outbreaks with more hospitalized cases represented a greater severity of illness and were more likely have food vehicles identified (Dominguez et al., 2009). Outbreaks led by a state health department or with assistance from the CDC were more likely to have a food vehicle identified when compared to outbreaks led by local or county health department (Jones, Imhoff, et al., 2004). If an analytic study – either a cohort study or case-control study – was conducted in addition to routine interviewing, a food vehicle was more likely to be identified (Jones et al., 2016). Outbreaks that occurred in restaurants or with catering were more likely to have an etiology identified (Jones, Imhoff, et al., 2004).

Although characteristics that contribute to the identification of an etiologic pathogen are well established, data on how these factors impact identification of a food vehicle are more limited and thus serve as the motivation for this project.

Colorado Foodborne Disease Outbreaks

In Colorado in 2018, there were 29 foodborne disease outbreaks reported, representing 538 illnesses, 7 hospitalizations, and 0 deaths. Foodborne disease outbreak investigations are led by either the local public health agency that the outbreak is located in or by the state health department if exposures span multiple jurisdictions or collaboratively by both local and state health departments. Ill cases, both laboratory confirmed and those epidemiologically linked to confirmed cases are reported via the Colorado Electronic Disease Reporting System (CEDRS). Disease reporting is a two-step process and requires both the clinical laboratory and the healthcare provider to report to the state health agency. Colorado is a decentralized public health structure (CSTE, 2020) with 64 counties and 14 regional epidemiologists who assist with leading foodborne disease outbreak investigations. The majority of the states' population (60%) resides in approximately 10% of local public health agencies, those that serve populations greater than 500,000 (CALPHO, n.d.). The majority of the population resides in the Denver Metro Area and is considered urban whereas the rest of the state is considered rural. Colorado reports foodborne outbreaks at a high number and rate when compared with other states. For example, in 2017, Colorado reported 44 foodborne disease outbreaks which represented a rate of between 6.52 – 14 foodborne disease outbreaks per one million population (CDC, 2019a). This rate of reporting belongs to the highest rate of reporting of foodborne disease outbreaks. As estimated by Scharff (2015) using his enhanced model, the mean cost per foodborne illness case is $1,925 in the United States. In comparison, Colorado has a mean cost per foodborne illness case of $2,096.

Purpose & Aims

The ability to identify a food vehicle in a foodborne disease outbreak depends on the capacity and efforts of state and local health departments to carry out surveillance and identify, investigate and respond to foodborne disease outbreaks. Barriers affecting the ability to identify a food vehicle can be categorized into outbreak characteristics and investigation methods. Analysis of these characteristics will identify those that are associated with outbreaks where food vehicles were identified, and shed light on what factors public health agencies should prioritize in foodborne disease outbreak investigations to identify food vehicles. Therefore, the aims of this study were to:

Aim 1: Identify factors associated with determining a food vehicle;

Aim 2: Compare factors associated with identifying a food vehicle between outbreaks detected by complaint-based surveillance versus pathogen-specific surveillance.

CHAPTER 2

Introduction

Foodborne illnesses are an important public health problem in the United States, accounting for an estimated 9.4 million domestically acquired illnesses attributable to pathogens of known etiology (Scallan, Hoekstra, et al., 2011) and 38.4 million domestically acquired illnesses attributable to pathogens of unknown etiology (Scallan, Griffin, et al., 2011) annually. These illnesses result in an estimated 127,839 hospitalizations and just over 3,000 deaths annually. While foodborne disease outbreaks represent a fraction of all foodborne illnesses, conducting outbreak investigations that identify and link causal pathogens with food vehicles are vital in order to remove unsafe foods from the market, improve food safety practices and policies, and identify novel or emerging pathogen-food vehicle pairings (Lynch et al., 2009). Despite the importance of outbreaks to food safety, the majority of foodborne disease outbreaks do not have an identified etiology and even fewer have a known food vehicle identified (Dewey-Mattia et al., 2018).

The ability to identify an etiology and food vehicle relies on the capacity and efforts of local public health agencies to conduct routine surveillance, and detect, investigate, and respond to foodborne disease outbreaks (Hoffmann et al., 2015). Previous research identified characteristics of confirmed outbreaks where an etiology was known including: known pathogen, specimen collection, case count, lead agency, outbreak setting, and conduct of analytic studies.

Identification of an etiologic pathogen is an important first step in outbreak investigation but there can be numerous reasons why an etiology is not identified, i.e., no specimens available for testing. Jones, Bulens, et al. (2004) concluded that in 68% of foodborne disease outbreaks without a known pathogen, two-thirds have no stool specimens submitted for testing but that collection of ≥ 1 stool specimen was significantly more likely to have an etiology identified. Rounds et al., (2010) also concluded that *Salmonella* outbreaks that start as clusters, that is identification by pathogen-specific surveillance, are more likely to be confirmed later on as outbreaks if there were ≥ 4 specimens versus 2, indicating that greater specimen collection can lead to identification of an etiology. Jones, Imhoff, et al. (2004) concluded that outbreaks involving ≥10 cases were significantly more likely to have had an etiology identified and consequently, larger outbreaks can result in greater specimen collection. Jones et al. (2016) concluded that the primary barrier for not pursuing additional epidemiological investigation when clusters of cases are identified is too few cases, highlighting the importance of having a sufficient case count in outbreak investigations. More outbreaks investigated by a state health department or with assistance by the CDC had an etiology identified when compared with outbreaks led by a local or county health department (Jones, Imhoff, et al., 2004). Conduct of an analytic study allows for the confirmation of an outbreak from a cluster (Jones et al., 2016). Most foodborne disease outbreaks were associated with restaurants or catered events, indicating that the exposure setting may be associated with an etiology being identified (Jones, Imhoff, et al., 2004).

Although characteristics that contribute to the identification of an etiologic pathogen are well established, the data is limited on how these factors impact identification of a food vehicle. Dominguez et al. (2009) examined differential features of foodborne outbreaks of known and unknown etiology of foodborne diseases reported from 2002 to 2005, in Spain, and concluded that characteristics associated with known food vehicle from the univariate analysis included: availability of samples from cases, hospitalization, availability of samples from food handlers, size ≥ 10 cases, availability of samples from food, and last year of the study period were significant; and from the multivariate analysis: hospitalization, size ≥ 10 cases, and the last year of the study period were significant. Therefore, human specimen, hospitalization, outbreak size were characteristics of foodborne outbreaks where etiology and food vehicle are known.

The purpose of this study was to identify and investigate characteristics and investigation methods of Colorado single state foodborne outbreaks that occurred between 2009 to 2019 where a food vehicle(s) was identified. Differences in whether a food vehicle was identified between the two modalities of how outbreaks are detected, that is either pathogen-specific surveillance or complaint-based surveillance, was also assessed in this study.

Methods

Data Source

Colorado outbreak data were available from 2009 to 2019 from the Colorado Department of Public Health and Environment's (CDPHE) REDCap based Outbreak Database (OBDB) and the Centers for Disease Control and Prevention's (CDC) National Outbreak Reporting System (NORS). Outbreak information is collected by epidemiologists at CDPHE and entered into OBDB. Once an outbreak investigation is complete, outbreak data is first entered into OBDB, reviewed for data completion, and then entered into NORS by the outbreak epidemiologist. Due to this directional flow of information, OBDB has many overlapping fields with NORS in order to capture all requisite outbreak information for NORS reporting; however, there are fields that are unique to OBDB, intended to capture fields of interest to CDPHE: public health agency that led the investigation, detection method of the outbreak – by complaint-based surveillance or by pathogen-specific surveillance, and the number of lab confirmed primary cases. NORS benefits from an annual systematic and formalized data entry and completeness review by CDC in addition to data cleaning efforts by CDPHE. As a result, NORS fields had less missing data when compared with the corresponding OBDB fields. Therefore, the primary source of data for the analysis dataset was extracted from NORS with the aforementioned three fields unique to OBDB merged with the NORS dataset to create the analysis dataset. Multistate outbreaks – those defined as a group of ill persons, living in two or more states, who were infected with the same bacterial strain (Marshall et al., 2020) – were excluded from this study.

Outcome

The outcome of the study was whether an outbreak had a known food vehicle or not. Outbreaks with known food vehicle reported as either confirmed or suspect to NORS, had outcome as yes, and was coded as 1. All other outbreaks where a food vehicle was not known (e.g., unknown) was the alternative, had outcome as no, and was coded as 0. Therefore, the unit of analysis was foodborne outbreaks.

Characteristics

The following variables were included in the analysis: pathogen, case count per outbreak, agency that led the outbreak, age group, hospitalization, investigation method, number of specimens collected, and geographical region where the outbreak occurred. Outbreaks were stratified by detection method: complaint-based – those reported by ill case(s) to public health – or pathogen-specific surveillance – those detected by routine surveillance. Characteristics of outbreaks detected by these two modalities were analyzed with regards to whether a food vehicle was identified

Pathogen was grouped into 5 categories: norovirus, bacteria, bacterial toxin, other, and unknown. Bacterial included *Salmonella*, *Campylobacter*, *Shigella*, Shiga toxin-producing *E. coli* (STEC), and *Listeria*. Bacterial toxin included *Bacillus*, *Clostridium* (*Clostridium botulinum*, *Clostridium perfringens*, and other *Clostridium* enterotoxins), staphylococci, and all bacterium classified as "other" but unspecified. Other included other viral pathogens (hepatitis and rotavirus), parasites (*Cyclospora* and *Toxoplasma*), and other agents (cleaning agents, other chemicals or toxins, plant or herbal toxins, scromboid, and *Vibrio*). Pathogens were defined as known if there was either a confirmed or suspect pathogen as routine testing is not performed for all pathogens (e.g., norovirus); unknown was defined as both unknown or missing.

Case count was a continuous variable describing the total number of primary cases per outbreak, which included both confirmed primary and probable cases. Outbreaks were categorized as "large" if they had ≥ 5 cases. Agency that led the outbreak denoted whether outbreak investigations were led by CDPHE or by a local public health agency. Outbreaks led by CDPHE represented a centralized outbreak investigation approach with greater investigation resources. Ages of cases that were part of outbreaks were reported in years, and was available as either a frequency, a percentage, or both, in different pre-set NORS age categories (e.g., number under 1 years of age, percent under 1 years of age, number age 1 to 4, and so on). New age group categories were created: pediatric (≤ 19 years of age), adults (20 to 74 years of age), and seniors (≥ 75 years of age). The missingness of data for frequency of cases in each age category versus the missingness of percentage of cases in each category were assessed and percentage was chosen as it had less missing data. For outbreaks where percentage age data was missing but frequency age data was not missing, the percentage was imputed and used in data analysis. Outbreaks were then categorized as those that were "majority pediatric" – i.e. outbreaks where more than 25% of the cases were reported to be pediatric aged – and those that were "majority senior" – i.e. outbreaks where more than 25% of the cases were reported to be senior aged.

Number of hospitalized cases was a continuous variable, describing the number of cases that were hospitalized per outbreak. Percent hospitalized was defined as the percentage of cases hospitalized in an outbreak. Investigation method was defined as outbreaks that had a routine investigation conducted (e.g., routine interviewing of cases only), outbreaks that also had an analytic study conducted (e.g., a case-control study or a cohort study), and outbreaks that utilized another method (e.g., food preparation review, water system assessment, treated or untreated recreational water venue assessment, investigation at factory/productive/treatment plant, investigation at original source, food product or bottled water traceback, environment/food/water sample testing, and other).

Setting was defined as the location where the food was consumed and was grouped into 5 broad categories: retail food establishments, private residences, other, institutions, and unknown. Retail food establishments included banquet facilities, caterers, fairs, festivals, other temporary or mobile services (i.e. food truck), and restaurants ("fast-food", buffet, sit-down dining, other or unknown types). Other settings included a farm or dairy, a hotel or motel, an office or an indoor workplace, a religious facility, and other. Institutions included hospitals, long-term care facilities, nursing homes, assisted living facilities, camps, schools, colleges, universities, prisons and jails. Unknown denotes outbreaks where the setting information was missing.

The number of specimens collected was a continuous variable and described the number of human specimens collected. NORS guidance recommends ≥ 2 samples to identify a potential outbreak worthwhile of investigation (CDC NORS, 2017). Primary lab confirmed cases is a variable used to strengthen specimen data as a lab confirmed case indicates that at least one specimen per case was collected and the pathogen confirmed. These two characteristics represent similar but different characteristics.

Geographical region described the county where the outbreak occurred; exposure can occur within a single county or within multiple counties. Single county outbreaks were further subdivided into whether they fell within the Foodborne Disease Active Surveillance Network (FoodNet) catchment area or outside it. FoodNet counties conduct population-based surveillance for laboratory-confirmed foodborne illnesses of certain pathogens (*Campylobacter, Cyclospora, Listeria, Salmonella,* STEC, *Shigella, Vibrio*, and *Yersinia*) in a collaborative partnership between CDC and CDPHE (CDC DFWED, 2021b) and have certain data quality standards that need to be met. The FoodNET counties in Colorado are comprised of the 5 main counties in the Denver urbanized metro area (Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas, and Jefferson) and was a proxy for urban regions versus non FoodNET counties, which was a proxy for rural regions. Additionally, the FoodNET catchment area represents the majority of the population of Colorado as well as a high concentration of public health agencies and resources.

Statistical Analysis

Univariate. Univariate analysis was conducted to determine associations between characteristics of outbreaks and the outcome of interest. For continuous characteristics, a two-sample t-test was performed due to large sample size meeting assumptions of normality for parametric tests. The Satterthwaite p-value was utilized as characteristics demonstrated unequal variance. Characteristics were determined to be significant if the p-value was < 0.05. For categorical characteristics, a chi-squared test was performed to assess whether a characteristic variable was associated with a food vehicle being identified. For characteristics where expected counts were ≥ 5, the chi-squared p-value was used. For characteristics where expected counts were < 5, Fisher's exact test was performed and the two-sided p-value was utilized. Characteristics were determined to be significant if the p-value was < 0.05.

Missing Data Analysis. Characteristics with > 80% missing data were excluded from analysis; therefore, specimen types other than human were not utilized in the analysis. Additionally, if either dataset – NORS or OBDB – demonstrated > 80% missingness for any characteristics due to variability in human data entry, the data source with the most complete data was used in the final analysis dataset and model building, typically NORS data.

Multivariable Logistical Regression Model. Multivariable logistic regression was performed to determine the final model that best predicts the success of outcome, that is food vehicle identified based on various outbreak and investigation characteristics. Other characteristics of interest that were determined to not be significant were forced into the final model for the most biologically reasonable model and based on previous literature: agency that led the outbreak, analytic studies, and average percent hospitalized cases. For ordinal variables, pathogen and setting, a reference category was chosen based on the most prevalent category. For pathogen, norovirus was chosen and for setting, retail food establishments were selected. All analyses were performed in SAS 9.4.

Results

Foodborne Disease Outbreak Demographics

There were 330 foodborne disease outbreaks reported in Colorado from 2009 to 2019 (Figure 1). Of these, 153 (46.4%) identified a food vehicle (Table 1). Of the 177 (53.6%) outbreaks without a food vehicle identified, 53 (16.1%) outbreaks had both an unknown etiology and an unknown food vehicle and 124 (37.6%) had a known etiology but an unknown food vehicle. Outbreaks with unknown etiology included only the "unknown" pathogen category; outbreaks with known etiology included norovirus, bacterial, bacterial toxin, and other pathogen categories.

Univariate Analysis

Food Vehicle Known Outbreaks compared with Food Vehicle Unknown Outbreaks: Pathogen was a characteristic that was significantly associated with having a food vehicle identified (p<.0001). Outbreaks with a known food vehicle(s) were primarily bacterial in etiology (38, 24.8%), followed by bacterial toxins (35, 22.9%) whereas outbreaks with an unknown food vehicle was mostly caused by norovirus (80, 45.2%) or an unknown pathogen (53, 29.9%) (Table 2). Outbreaks with known food vehicles were larger with an average of 16.4 cases (median 8 cases) per outbreak and 93 (60.8%) outbreaks that were "large", compared with outbreaks with unknown food vehicle with an average of 12.1 cases (median 6 cases) per outbreaks and 101 (57.1%) outbreaks that were "large". Case count (p=0.0283) and specifically outbreaks with larger case counts were significantly associated with outbreaks with known food vehicles (p=0.0366). The majority of outbreaks with known food vehicles were led by local public health agencies (126, 82.4%), which was similar for outbreaks with unknown food vehicles (169, 95.5%). Local led outbreaks were significantly associated with having a food vehicle known (*p*<.0001). A small percentage of outbreaks with known food vehicles (8.3%±20.9%) had hospitalized cases, with a mean of 0.8±3.5 cases per outbreak, compared with a mean of 0.2±0.6 cases per outbreak for unknown food vehicles. Hospitalized cases were significantly associated with having a food vehicle identified (*p*=0.0230). Of outbreaks with known food vehicles, 66 (43.1%) of cases were investigated with routine investigation, 78 (51.0%) were investigated with analytic studies, and 9 (5.9%) were investigated with other method(s), compared with outbreaks with unknown food vehicles, which had less analytic studies conducted (67, 37.9%), more investigations conducted with other methods (20, 11.3%), and approximately 50.8% (90) conducted with routine investigation. Analytic study was significantly associated with outbreaks with known food vehicles (*p*=0.0166). The majority of outbreaks occurred in retail food establishments for both known food vehicles (78, 51.0%) and unknown food vehicles (118, 66.7%); setting was significantly associated with outbreaks with known food vehicle (*p*=0.0004).

Approximately 70% (107) of outbreaks with known food vehicles had information on human specimen collection summing up to a total of 497 specimens collected, which was comparable to unknown food vehicles which had 116 (65.5%) outbreaks with specimen collection summing to a total of 467 specimens. This translates to a mean of 4.6±7.1 specimens collected per outbreak for known food vehicles and 4.0±835 for unknown. Using the criteria of $\geq$ 2 human specimens collected, 77 (72.0%) of outbreaks with known food vehicles met this cut-off point, which was not significant (*p*=0.4441), compared with 93 (80.2%) of unknown food vehicles with ≥ 2 specimens collected. Among outbreaks with known food vehicles, 136 (88.9%) outbreaks had data on primary lab confirmed cases, representing a mean of 3.3 ±6.5 cases per outbreak and 158 (89.3%) of outbreaks with unknown food vehicles had a mean of 1.3±2.2 cases; this was also significantly associated with identifying a food vehicle. The majority of outbreaks with known food vehicle occurred in a single county (140, 91.55%), similarly to unknown food vehicles (174, 98.3%) which was not significant. However, although the minority of outbreaks with known food vehicles occurred in multiple counties, (13, 8.5%), this was significantly associated with identifying a food vehicle (*p*=0.0041).

Food Vehicle Known Outbreaks compared with Food Vehicle Unknown Outbreaks, Complaint-based Detection: Outbreaks with known food vehicle(s) were primarily bacterial in etiology (34, 29.3%), followed by unknown etiology (33, 28.4%), compared with norovirus (80, 50.3%) followed by unknown (53, 33.3%) for unknown food vehicle (Table 3). Pathogen was a characteristic that was significantly associated with having a food vehicle identified (p<.0001). Outbreaks with known food vehicles had on average, 16.4 ± 19.4 cases with a median of 9 cases per outbreak and 75 (64.7%) outbreaks that were "large", compared with an average case count of 12.1±14.2, a median of 7 cases per outbreak, and 96 (60.4%) outbreaks that were "large" for unknown food vehicle. A minority of outbreaks with known food vehicles (5.2%±15.3%) had hospitalized cases, with a mean of 0.3±0.9 cases per outbreak compared with 1.4%±7.1% hospitalized cases for unknown food vehicle, with a mean of 0.1±0.5 hospitalized cases. Outbreaks with hospitalized cases were significantly associated with having a food vehicle identified (p=0.0217). The use of either routine investigation (49, 42.2% for known food vehicles; 83, 52.2% for unknown food vehicles) or of an analytic study (60, 51.7% for known food vehicles; 59, 37.1% for unknown food vehicles) were both significantly associated with a food vehicle being identified, with analytic studies being more significant (p=0.0217) than routine investigation alone (p=0.0326). The majority of known outbreaks that were complaint-based in detection occurred in retail food establishments for both known food vehicles (57, 49.1%) and unknown food vehicles (103, 64.8%); setting was significantly associated with outbreaks with known food vehicle (p=0.0140).

Approximately 72.1% (72) of outbreaks with known food vehicles had information on human specimen collection (p=0.9737) summing up to a total of 204 specimens collected. This translates to a mean of 2.8±1.9 specimens collected per outbreak (p=0.6567). Similarly, outbreaks with unknown food vehicle had 62.3% (99) outbreaks with specimens collected, representing a mean of 3.0±3.0 samples per outbreaks, and a total of 297 specimens collected.

Food Vehicle Known Outbreaks compared with Food Vehicle Unknown Outbreaks, Pathogen-specific Surveillance Detection: Outbreaks with known food vehicles had on average, 16.7 ± 29.4 cases (p=0.0268) with a median of 4 cases per outbreak and 18 (48.6%) outbreaks that were "large" (p=0.0296), compared with unknown food vehicles which had on average, 5.3±4.3 cases with a median of 4.5 cases per outbreak and 5 (27.8%) "large" outbreaks; case count was significantly associated with having a food vehicle known. Agency that led the outbreak was also significantly associated with a food vehicle being identified, with the majority being led by local agencies (known food vehicle 20, 54.1%; unknown food vehicles 16, 88.9%; *p*=0.0108). Lastly, an outbreak that had multi-county exposure was in the minority with known food vehicle outbreaks (7, 18.9%) – none for outbreaks with unknown food vehicles – but was also significantly associated with whether a food vehicle was identified (*p*=0.0482).

Multivariable Logistical Analysis

Backward selection yielded inclusion of: pathogen and number of lab confirmed cases, in order of significance. Stepwise selection yield inclusion of: pathogen and number of lab confirmed cases, in order of significance. Therefore, model selection yields the following model:

$$logit(P(Food\ Vehicle\ Undetermined\ (0))) = \beta_0 + \beta_1 Pathogen + \beta_2 NumberofLabConfirmedCases + \varepsilon$$

Although number of lab confirmed cases was selected to be significant, this does not accurately represent case count per outbreak therefore, estimated primary was substituted. The setting of outbreak exposure, the agency that lead the outbreak, conducting an analytic outbreak, and mean percent of hospitalized cases were also chosen to be included in the analysis as per the following model:

$$logit(P(Food\ Vehicle\ Undetermined\ (0))) = \beta_0 + \beta_1 Pathogen + \beta_2 Setting + \beta_3 EstimatedPrimary + \beta_4 LeadAgency + \beta_5 Analytic + \beta_6 AvgPctHosp + \varepsilon$$

The odds of an outbreak with bacterial etiology of having a food vehicle identified was more than three times the odds of norovirus outbreaks (OR=3.44, 95% CI: 1.52-7.78) (Table 5). Similarly, outbreaks with etiology of bacterial toxin were approximately six times the odds of norovirus outbreaks of having a food vehicle identified (OR=5.97, 95% CI: 2.80-12.73). "Other" etiology was approximately eleven times the odds of norovirus outbreaks to have a food vehicle identified (OR=10.87, 95% CI: 3.41-34.69). The odds of outbreaks of bacterial (*p*=0.0031), bacterial toxin (*p*<.0001), and "other" (*p*<.0001) etiologies being more likely than norovirus outbreaks to have a food vehicle identifies were statistically significant.

The odds of an outbreak with a food vehicle known with exposure in a private residence (OR=2.17, 95% CI: 1.09-4.30) was more than double the odds of an outbreak with exposure in a retail food establishment and this difference was statically significant. With every increase of 1 case per outbreak, odds of a food vehicle being identified increases by 2% (OR=1.02, 95% CI: 1.00-1.04). For every outbreak investigation led by CDPHE, the odds of a food vehicle being identified was triple the odds of outbreak investigations led by local public health agencies (OR=2.99, 95% CI: 1.14-7.89). Although analytic studies and percentage of cases were included in the model for their importance in outbreak investigations, neither was significant for a food vehicle being identified.

Discussion

Characteristics that were associated with outbreaks with a known food vehicle were: pathogen, case count, agency that led the outbreak, age group, hospitalization, and conducting an analytic investigation. Outbreaks with known food vehicle were of bacterial etiology, larger in size, more likely to be led by CDPHE, had more outbreaks with majority pediatric cases, had more outbreaks with hospitalized cases, conducted an analytic study, and had more specimens collected. In contrast, outbreaks with unknown food vehicle were norovirus in etiology, smaller in size, more likely to be led by local public health agencies, had more outbreaks with majority senior cases, had less hospitalized cases, conducted routine investigation only, and had less specimens collected.

Norovirus is the leading cause of foodborne disease outbreaks and associated illnesses in the United States (Dewey-Mattia et al., 2018; Wikswo et al., 2021) and was also the primary etiology of unknown food vehicles. Bacterial pathogens – *Salmonella, Shigella*, Shiga toxin-producing *E. coli* (STEC), *Campylobacter*, and *Listeria* – as a group comprise the other most commonly reported outbreak associated etiologies and was the primary etiology for known food vehicles. Most norovirus outbreaks are associated with ready-to-eat food products, contaminated during preparation by an ill food handler (Dewey-Mattia et al., 2018), representing a point-source contamination of a food vehicle (Wikswo et al., 2021) that can also subsequently result in person to person transmission as well. In contrast, bacterial pathogens, especially *Salmonella*, *Campylobacter*, and

STEC, were associated more with upstream contamination of food products that are then prepared and consumed in a variety of settings versus a point-source contamination (Wikswo et al., 2021). Furthermore, norovirus spreads easily, has a low infectious dose but high transmissivity (Wikswo et al., 2021); laboratory testing and confirmation is not routine or required for norovirus outbreaks to confirm etiology in Colorado.

It can be challenging to identify a food vehicle in norovirus outbreaks due to these reasons: difficulty to differentiate between primary foodborne transmission versus secondary person-to-person or environmental transmission, potential contamination of multiple food vehicles during preparation, especially with regards to ready-to-eat food products, lack of specimens and testing. Additionally, there lacks a robust pathogen-specific surveillance system for norovirus and most Colorado foodborne norovirus outbreaks are predominantly detected by complaint from ill cases. In contrast, bacterial pathogens are detected more often by pathogen-specific laboratory surveillance in Colorado, and reported to PulseNet, a national laboratory network that began in 1996, aimed to aid outbreak investigation and identification of food sources (CDC DFWED, 2021c). Previous literature on common pathogen-food pairs responsible for previous outbreaks may guide the way that outbreak investigations are tailored towards a suspected pathogen or food vehicle and may result in confirmation of the suspect vehicle (Jones, Imhoff, et al., 2004).

Outbreaks with larger case counts were associated with outbreaks with known food vehicles, a trend that persisted regardless of detection method. Outbreaks with known food vehicles had not only greater case counts, that is average cases per outbreak, but a bigger proportion of "large" outbreaks when compared to those with unknown food vehicles. Larger outbreaks have numerous factors that can result in identification of a food vehicle: greater number of specimens collected (Jones, Bulens, et al., 2004; Jones, Imhoff, et al., 2004), more ill cases and epidemiologic data, and likely better at differentiating between situations of sporadic acute illnesses and a true outbreak with a common exposure (Jones, Imhoff, et al., 2004). Jones, Imhoff, et al. (2004) also states that larger outbreaks were more likely to have been investigated thoroughly. Both Dominguez et al. (2009) and Jones, Imhoff, et al. (2004) state that ≥ 10 cases is associated with identification of a food vehicle and etiology, respectively. However, in this analysis, a case count of ≥ 5 was significant to identify a food vehicle.

Outbreaks with known food vehicles were more likely to have more outbreaks where the majority was pediatric aged which is in contrast with outbreaks with unknown food vehicles, which were more likely to have majority senior aged cases. Outbreaks with majority pediatric cases are also more likely to be prioritized and receive more investigation resources. Food consumption behaviors and preference for certain foods can vary by age, which can contribute to food vehicles being identified. For example, the handling and consumption of raw dough is common among children, and an outbreak of STEC associated with cookie dough that disproportionately affected pediatric cases led to the identification of STEC in flour as not only a food vehicle, but a novel pathogen-vehicle pairing in 2016 (Marshall et al., 2020). Conversely, norovirus, which has already been established to be associated with outbreaks with unknown food vehicles, occurs most commonly in long-term care facilities (Wikswo et al., 2021), which disproportionately houses an older population.

Outbreaks with known food vehicles are associated with a greater proportion of hospitalized cases, in contrast with outbreaks with unknown food outbreaks, which have a much smaller proportion. Hospitalized cases may be interpreted as a reflection of the severity of an outbreak as vulnerable populations, such as the elderly or those with an underlying health condition are particularly susceptible (Dominguez et al., 2009; Scallan, Hoekstra, et al., 2011). Outbreaks with bacterial etiology that results in larger outbreaks are the most common causes of hospitalizations in foodborne illnesses due to greater severity and duration of illness (Dewey-Mattia et al., 2018), which is in accordance with having a food vehicle identified.

Outbreaks with known food vehicles were more likely to be led by CDPHE when compared with outbreaks with unknown food vehicle which were more likely to be led by local agencies. This finding is in agreement with Jones, Imhoff, et al.'s (2004) conclusions that larger outbreaks are typically led by state and federal agencies however, it is not clear whether this association can be attributable to a natural bias for larger agencies to investigate larger outbreaks where the there is a greater likelihood of identifying a food vehicle regardless of the lead agency, or due to having adequate resources for outbreak investigation and response. In Colorado, what impacts identification of a food vehicle depends more significantly is whether an exposure happened in a single county versus multiple counties, which may reflect collaboration between multiple counties to share resources or may reflect situations where investigation demands surpass the resources of local agencies therefore, CDPHE may lead the outbreak investigation instead. A better understanding of this interaction and when CDPHE versus local agencies lead multi-county outbreak investigations may be a worthwhile area for future study.

Furthermore, conduct of an analytic study was associated with outbreaks with known food vehicles, which are predominantly carried out by agencies with greater resources. For example, Schlinkmann et al. (2017) examined characteristics of foodborne outbreaks between those with an analytic study carried out and those without and the impact on identifying a food vehicle from 2007 – 2011 in the European Union, and stated that analytic studies – principally cohort studies and case-control studies – could increase the likelihood of identifying a food vehicle, but was not commonly applied, particularly by local health departments.

Among outbreaks detected by complaint-based, pathogen, hospitalized cases, investigation method, and exposure setting were significantly associated with a food vehicle being identified. This is in contrast with outbreaks detected by pathogen-specific surveillance, where case count and lead agency were significantly associated with a food vehicle being identified. In outbreaks detected by pathogen-specific surveillance, pathogen was no longer significant since unknown pathogens would not be detected by laboratory methods.

In outbreaks detected by pathogen specific surveillance, having a greater case count and having a "larger" outbreak was more significantly associated with having a food vehicle being identified, similar to previous findings. In comparison, outbreaks detected by complaint with a food vehicles identified, had a higher proportion of hospitalized cases, which was significant. More hospitalized cases reflect greater severity of disease, which has been established as attributable to bacterial pathogens and outbreaks with known food vehicle. Norovirus, associated with unknown food vehicle outbreaks, can result in a larger case count per outbreak but less severity of illness, and would be more likely to be detected by complaint, i.e., reporting to public health from a long-term care facility, childcare setting, ill cases , etc. (Wikswo et al., 2021). Outbreaks detected by pathogen specific-surveillance with known food vehicle are more likely to be led by local public health agencies. Local agencies are responsible for routine interviewing of cases in their jurisdiction; local agencies are more likely to identify an outbreak if they centralize surveillance and interviewing of ill cases by pathogen.

Limitations

Prior to 2018, foodborne outbreak information was entered into an Access database, which only had the ability to hold 100 unique fields therefore, this database was unable to capture all of the data required for outbreak reporting to NORS. Outbreak data from the Access database was imported into the new REDCap OBDB but there were issues during the import process where certain fields did not port over to the new OBDB fields. For example, hospitalization and death data were two fields where there may have been some data loss due to the import process; fortunately, NORS contained more complete hospitalization data. Additionally, the old Access database had more users than the new REDCap database which represents many more points for gaps in data quality and completeness. These noticeable differences in data quality and completeness, both prior to 2018 versus after 2018, as well as between users, were some of the reasons why NORS data was ultimately chosen for the majority of outbreak fields given their completeness and accuracy. Since the REDCap OBDB has been activated, there have been no previous analysis of the quality and completeness of data entry, which may be a valuable future project to undertake.

Missing data in both REDCap and NORS was a challenge to analyze at times as it was unclear whether this data was truly missing, unknown, or just was not entered due to user error as all 3 scenarios were observed during data cleaning. Occasionally, missing data could be imputed from other fields but otherwise, missing and unknown data were often grouped together. The large degree of missing data for certain fields in both REDCap and NORS likely indicates a procedural gap in staff training and data entry. Future training and a formalized process for staff performing data entry for both REDCap and NORS would also be a valuable project. Jones, Imhoff, et al. (2004)discusses the high degree of variability in reporting of outbreaks involving only 2 or 3 cases as being dependent on the interpretation, resources, and priorities of persons responsible for investigating and reported outbreaks in each state; an effect that is less pronounced in larger outbreaks. Therefore, this also indicates an opportunity for improvement in training for staff carrying out outbreak investigation across all levels of public health as well as standardizing outbreak investigation priorities.

By definition, pathogen-specific surveillance includes outbreaks that have already been detected and thus the pathogen is known. This also introduces selection bias into the outcome as outbreaks classified as detected by pathogen-specific surveillance would exclude all outbreaks where laboratory confirmation was not able to be obtained. For example, outbreaks of unknown etiology would be excluded from analysis completely and outbreaks that are of norovirus or bacterial toxin in etiology would be less likely to be identified as routine testing of these outbreaks occur infrequently in Colorado.

Future Directions

Resources to investigate outbreaks can be limited at times so guidance in prioritizing various characteristics can aid in increased identification of food vehicle(s). An area of future research can include an analysis of timeliness of human specimen collection and recovery at the lab and whether more timely identification of etiology can result in more food vehicles being identified. As documented, unknown etiologies can pose a barrier in identifying food vehicle(s); a greater proportion of outbreaks with known etiologies are associated with known food vehicles. Jones, Bulens, et al. (2004) stated that when stool collection kits were delivered to and from ill cases to improve rates of specimen recovery, this could result in the reduction of outbreaks with unknown etiologies. Prior to COVID, local public health agencies were responsible for facilitating the delivery and return of stool kits, often requiring staff to physically drive and drop off stool collection kits and subsequently pick them up from ill cases' residences. Since COVID, stool kit delivery has now been centralized to CDPHE; prepacked, self-contained stool kits are sent via courier direct to ill cases' residences overnight, similar to the pilot test conducted by Jones, Bulens, et al. (2004). Sending out stool kits to other epidemiologically linked ill cases who have not sought medical care and testing can also result in increased collection of outbreak information. Although ill cases are responsible for dropping off stool kits with their local public health office, CDPHE couriers visit each agency daily to collect specimens. The impact of this centralized stool kit delivery system and speed of delivery should be analyzed in the future to see whether this novel method has resulted in increased specimen collection and outbreaks with identified etiologies and food vehicle(s).

Outbreaks with analytic studies conducted are associated with having a food vehicle identified therefore, direction of investigation resources to conducting analytic studies can lead to a greater proportion of outbreaks with food vehicle(s) being identified. For outbreaks of particular public health interest or concern, especially for those detected by complaint-based, the design and implementation of an analytic study could yield identification of food vehicle(s). Additionally, since the majority of outbreaks were detected by complaint-based methods, more resources could be implemented to facilitate reporting by the public to public health of foodborne illnesses and foodborne disease outbreaks. An area of future research should examine whether counties with a robust system for reporting of foodborne illnesses by the public leads to a greater proportion of outbreaks that results in food vehicles being identified, in comparison to counties with less robust reporting systems.

Conclusion

In summary, this study concluded that pathogen, case count, lead agency, hospitalization, conduct of an analytic study, and geographic location of exposure were significantly associated with increased identification of a food vehicle in single state Colorado foodborne outbreaks by univariate analysis. Multivariate modelling concluded that pathogen, case count, and lead agency were significant in identification of food vehicles; specifically, larger case counts, outbreaks of bacterial pathogen, and outbreak investigations led by CDPHE had strong associations with a food vehicle being identified.

CHAPTER 3

Conclusions

Foodborne illnesses are an important public health problem in the United States. Although foodborne outbreaks represent a fraction of all foodborne illnesses, they provide critical information on the pathogens, foods, and food-pathogen pairs causing illness. The data from outbreak investigations are then used to guide food safety regulations, policies, and practices. By describing the investigation methods and characteristics associated with identifying an outbreak food vehicle, our goal was to aid public health agencies in prioritizing outbreaks and identify approaches which result in greater success of determining food vehicles. These recommendations can also improve outbreak investigation processes at smaller public health agencies or guide less experienced investigators.

Findings and Recommendations

Analyzing 2009-2019 single state foodborne outbreaks that occurred in Colorado, outbreaks with an identified food vehicle were more likely to have a known etiology and be bacterial, had larger case counts, were led by CDPHE, had a greater proportion of hospitalized cases, had an analytic study conducted, exposure in private residences, and were more likely to have had multi-county exposure, compared to outbreaks with unknown food vehicle. These findings suggest that larger outbreaks, outbreaks with greater severity of illness, and outbreaks with multi-county exposures, were more likely to be led by CDPHE and to have analytic studies carried out. Some of these findings seem apparent – larger outbreaks, whether in size or in geographical spread, or those with a higher burden of ill cases – are more likely to garner more media attention and/or receive greater investigative resources, likely coordinated and led by the state health department. In general, actionable recommendations from these findings for all public health agencies would be to have a greater focus and effort on: (1) identifying an etiology through specimen collection and testing; (2) finding additional cases if initial case counts are small; and (3) diverting some staffing resources to conducting an analytic study in addition to routine interviewing. The other characteristics of significance –

severity of illness and multi-county exposure – are not modifiable as they describe characteristics of the outbreak as opposed to characteristics of investigation methods.

For outbreaks that were detected by complaint-based surveillance, those with a known food vehicle were more likely to have a known etiology and be bacterial in etiology. Outbreaks were also more like to have a greater proportion of hospitalized cases as well as having an analytic study conducted. These outbreaks typically start with reports from ill cases who likely may not have yet sought testing yet or who may not have received the appropriate test; there may also be additional ill cases, i.e., dining companions from the same household. Outbreaks with known food vehicles detected by complaint were also more likely to occur in retail food establishments. Actionable recommendations from these findings for all public health agencies would be to: (1) identify all ill cases associated with the common exposure and recommend testing; (2) more rapid initiation of an analytic study, such as a cohort-study for restaurant outbreaks; and (3) increased collaboration with environmental health partners, who may be receiving the initial illness complaints so that investigations can start sooner.

Outbreaks detected by pathogen-specific surveillance, with a known food vehicle were more likely to have a larger outbreak size and case count but more likely to be led by local public health agencies, and more likely to have multi-county exposure, all of which were statistically significant. This suggests that outbreaks detected by pathogen-specific surveillance are more likely to be investigated by local agencies, likely in the process of carrying out routine communicable disease work. Additionally, these outbreaks are more likely to have multi-county exposure, which is in agreement with a larger outbreak size. These outbreaks may indicate scenarios where one affected county leads the outbreak investigation with support and collaboration with other affected counties. These findings suggest that guidance for local public health agencies regarding outbreak investigation with the goal of identifying a food vehicle would be most effective for outbreaks detected by pathogen-specific surveillance, and should focus on increasing case finding and facilitating collaboration.

Applicability of Recommendations

Many of these findings and recommendations support the existing recommendations set forth by the Council to Improve Foodborne Outbreak Response (CIFOR) Guidelines for Foodborne Disease Outbreaks Response toolkit (CIFOR, 2019), a cornerstone for the training of staff in local and state public health, environmental health, and food regulatory agencies and laboratories in the realm of foodborne disease outbreak response. The CIFOR toolkit is intended to assist agencies in identifying areas of foodborne disease outbreak detection and response that may benefit from improvement and facilitate identification and implementation of appropriate CIFOR recommendations. Specific recommendations regarding increasing specimen collection for the goal of identifying etiology, conducting an analytic study, and increased inter-agency collaboration – both between state and local and between local agencies –should be considered for future sources of public health funding. For example, outbreaks where routine molecular subtyping of all isolates were more likely to be have an etiology identified and consequently, greater success for identifying a food vehicle (Jones et al., 2013). Therefore, consistent and adequate funding to the state laboratory should be maintained to carry out routine and outbreak surge testing. Carrying out needs assessments of each public health agency's unique capacity and needs are important steps to implementing data-driven targeting of funding and resources (Jones et al., 2013). Additionally, these recommendations should be considered for dissemination by the Colorado Integrated Food Safety Center of Excellence (CoE), and in their trainings targeted towards providing state and local health departments with increased capacity to track and investigate foodborne illnesses and outbreak investigations (CSPH, 2021).

Since the start of the COVID pandemic, adequate staffing at local and state public health agencies to carry out investigations of foodborne illnesses and outbreaks have been greatly diminished; these effects have also been compounded by staff turnover and attrition due to a variety of factors, i.e. burnout. This has led to a reduction of staff experienced with foodborne illnesses and investigation of foodborne disease outbreaks; a lack of experienced staff has also led to a reduction of trainers for new staff. As training centers such as the CoE attempt to meet the training needs of public health agencies in Colorado, this is an appropriate time to re-evaluate existing training tools and resources to include the recommendations of this project as well as increasing the efficiency of outbreak investigations with regards to identification of food vehicles. Next steps include providing the findings and recommendations of this study to CDPHE and other local public health agencies in prioritizing investigations characteristics in the form of updated trainings with the CoE.

Additionally, findings on the data quality and completeness of the OBDB will be shared with CDPHE; namely the variability in data entry resulting in a high proportion of missing data. This project served as the first audit of data quality in OBDB after its implementation in 2018. Previously, outbreak data was captured in an Access database that was more limited in the number of fields and responses that it could capture; since the transition, no systematic analysis of how well data migration from the Access Database to the OBDB has occurred nor has an analysis of how outbreak data is entered in OBDB has been performed. During data analysis, it was noted that there was variability of data entry between epidemiologists which resulted in missing data. Therefore, future steps should consider a more unified and formalized training protocol for epidemiologists performing data entry into OBDB as well as implementation of a plan for regular audits of data.

The goal of this project was to identify characteristics of foodborne disease outbreaks where a food vehicle was identified in the hopes of creating recommendations and guidance to promote implementation of these characteristics for future outbreak investigations. A knowledge gap of these characteristics, specific to single-stage Colorado outbreaks initiated this analysis. With the COVID pandemic, there is now further need to identify investigation characteristics to be prioritized as well as novel approaches to dissemination of this information and future training opportunities. Partnership between CDPHE and the CoE to adopt these recommendations and translate into model practices can lead to greater success in identifying food vehicles in future outbreaks.

REFERENCES

CALPHO. (n.d.). *Colorado Public Health History* . Http://Www.Calpho.Org/Uploads/6/8/7/2/68728279/Co_public_health_history.Pdf.

CDC. (2019a). *Surveillance for Foodborne Disease Outbreaks, United States, 2017, Annual Report*. http://www.cdc.gov/foodsafety/fdoss/

CDC. (2019b). National Outbreak Reporting System Dashboard. In *https://wwwn.cdc.gov/norsdashboard*.

CDC DFWED. (2018, June 20). *Steps in a Foodborne Outbreak Investigatoin*. Https://Www.Cdc.Gov/Foodsafety/Outbreaks/Investigating-Outbreaks/Investigations/Detection.Html.

CDC DFWED. (2021a, June 3). *Timeline for Identifying and Reporting Illnesses in Foodborne Outbreaks*. Https://Www.Cdc.Gov/Foodsafety/Outbreaks/Investigating-Outbreaks/Reporting-Timeline.Html.

CDC DFWED. (2021b, September 23). *About FoodNet*. Https://Www.Cdc.Gov/Foodnet/about.Html.

CDC DFWED. (2021c, September 29). *About PulseNet*. Https://Www.Cdc.Gov/Pulsenet/about/Index.Html.

CDC NORS. (2017). *National Outbreak Reporting System (NORS) Guidance For: Reporting all foodborne and enteric person-to-person, environmental, animal contact, and unknown/indeterminate mode of transmission outbreaks and for reporting the general section of waterborne outbreaks*. https://www.cdc.gov/nors/downloads/form-52-13.pdf

CIFOR. (2019). *CIFOR Guidelines for Foodborne Disease Outbreaks Response Toolkit*. https://cifor.us/downloads/clearinghouse/Second-Edition-of-the-CIFOR-Guidelines-Toolkit-Full-Version_Updated-Links.pdf

CSPH. (2021). *Colorado Integrated Food Safety Center of Excellence*. Https://Coloradosph.Cuanschutz.Edu/Research-and-Practice/Centers-Programs/Foodsafety.

CSTE. (2020, November 13). *Health Department Governance*. Https://Www.Cdc.Gov/Publichealthgateway/Sitesgovernance/Index.Html.

Dewey-Mattia, D., Manikonda, K., Hall, A. J., Wise, M. E., & Crowe, S. J. (2018). *Surveillance for Foodborne Disease Outbreaks - United States, 2009-2015. MMWR Surveill Summ 2018;67(No. SS-10):[1-11]*.

Dominguez, A., Broner, S., Torner, N., Martinez, A., Jansa, J. M., Alvarez, J., Barrabeig, I., Cayla, J., Godoy, P., Minguell, S., Camps, N., & Sala, M. R. (2009). Differential Features of Foodborne Gastroenteritis Outbreaks of Known and Unknown Etiology. *Journal of Food Protection*, *72*(9), 1958–1962. http://meridian.allenpress.com/jfp/article-pdf/72/9/1958/1681886/0362-028x-72_9_1958.pdf

Hedberg, C. W., Greenblatt, J. F., Matyas, B. T., Lemmings, J., Sharp, D. J., Skibicki, R. T., & Liang, A. P. (2008). Timeliness of Enteric Disease Surveillance in 6 US States. *Emerging Infectious Diseases*, *14*(2), 311–313. http://www.cdc.gov/stdconference/

Hoffmann, S., Maculloch, B., & Batz, M. (2015). *Economic Burden of Major Foodborne Illnesses Acquired in the United States*. www.ers.usda.gov

Jones, T. F., Bulens, S. N., Gettner, S., Garman, R. L., Vugia, D. J., Blythe, D., Hawkins, M. A., Monroe, S. S., Angulo, F. J., & Parashar, U. D. (2004). Use of Stool Collection Kits Delivered to Patients Can Improve Confirmation of Etiology in Foodborne Disease Outbreaks. *Clinical Infectious Diseases*, *39*, 1454–1459. https://academic.oup.com/cid/article/39/10/1454/457886

Jones, T. F., Imhoff, B., Samuel, M., Mshar, P., McCombs, K. G., Hawkins, M., Deneen, V., Cambridge, M., & Olsen, S. J. (2004). Limitations to Successful Investigation and Reporting of Foodborne Outbreaks: An Analysis of Foodborne Disease Outbreaks in FoodNet Catchment Areas, 1998–1999. *Foodborne Outbreaks*, *38*, S297–S302.

Jones, T. F., Rosenberg, L., Kubota, K., & Ingram, L. A. (2013). Variability among states in investigating foodborne disease outbreaks. *Foodborne Pathogens and Disease*, *10*(1), 69–73. https://doi.org/10.1089/fpd.2012.1243

Jones, T. F., Sashti, N., Ingram, A., Phan, Q., Booth, H., Rounds, J., Nicholson, C. S., Cosgrove, S., Crocker, K., & Gould, L. H. (2016). Characteristics of Clusters of Salmonella and Escherichia coli O157 Detected by Pulsed-Field Gel Electrophoresis that Predict Identification of Outbreaks. *Foodborne Pathogens and Disease*, *13*(12), 674–678. https://doi.org/10.1089/fpd.2016.2171

Jones, T. F., & Yackley, J. (2018). Foodborne Disease Outbreaks in the United States: A Historical Overview. *Foodborne Pathogens and Disease*, *15*(1), 11–15. https://doi.org/10.1089/fpd.2017.2388

Kase, J. A., Zhang, G., & Chen, Y. (2017). Recent foodborne outbreaks in the United States linked to atypical vehicles — lessons learned. In *Current Opinion in Food Science* (Vol. 18, pp. 56–63). Elsevier Ltd. https://doi.org/10.1016/j.cofs.2017.10.014

Li, J., Shah, G. H., & Hedberg, C. (2011). Complaint-based surveillance for foodborne illness in the United States: A survey of local health departments. *Journal of Food Protection*, *74*(3), 432–437. https://doi.org/10.4315/0362-028X.JFP-10-353

Lynch, M. F., Tauxe, R. v., & Hedberg, C. W. (2009). The growing burden of foodborne outbreaks due to contaminated fresh produce: Risks and opportunities. *Epidemiology and Infection*, *137*(3), 307–315. https://doi.org/10.1017/S0950268808001969

Marshall, K. E., Nguyen, T.-A., Ablan, M., Nichols, M. C., Robyn, M. P., Sundararaman, P., Whitlock, L., Wise, M. E., & Jhung, M. A. (2020). Investigations of Possible Multistate Outbreaks of Salmonella, Shiga Toxin–Producing Escherichia coli, and Listeria monocytogenes Infections — United States, 2016. *MMWR Surveillance Summaries*, *69*(No. SS-6), 1–14. https://doi.org/http://dx.doi.org/10.15585/mmwr.ss6906a1

ODPHP. (2021). *Food Safety | Healthy People 2020*. Https://Www.Healthypeople.Gov/2020/Topics-Objectives/Topic/Food-Safety.

Rounds, J. M., Boxrud, D. J., Jawahir, S. L., & Smith, K. E. (2012). Dynamics of Escherichia coli O157:H7 outbreak detection and investigation, Minnesota 2000-2008. *Epidemiology and Infection*, *140*(8), 1430–1438. https://doi.org/10.1017/S0950268811002330

Rounds, J. M., Hedberg, C. W., Meyer, S., Boxrud, D. J., & Smith, K. E. (2010). Salmonella enterica pulsed-field gel electrophoresis clusters, Minnesota, USA, 2001-2007. *Emerging Infectious Diseases*, *16*(11), 1678–1685. https://doi.org/10.3201/eid1611.100368

Scallan, E., Griffin, P. M., Angulo, F. J., Tauxe, R. v., & Hoekstra, R. M. (2011). Foodborne illness acquired in the United states-Unspecified agents. *Emerging Infectious Diseases*, *17*(1), 16–22. https://doi.org/10.3201/eid1701.P21101

Scallan, E., Hoekstra, R. M., Angulo, F. J., Tauxe, R. v., Widdowson, M. A., Roy, S. L., Jones, J. L., & Griffin, P. M. (2011). Foodborne illness acquired in the United States-Major pathogens. *Emerging Infectious Diseases*, *17*(1), 7–15. https://doi.org/10.3201/eid1701.P11101

Scharff, R. L. (2012). Economic burden from health losses due to foodborne illness in the united states. *Journal of Food Protection*, *75*(1), 123–131. https://doi.org/10.4315/0362-028X.JFP-11-058

Scharff, R. L. (2015). State estimates for the annual cost of foodborne illness. *Journal of Food Protection*, *78*(6), 1064–1071. https://doi.org/10.4315/0362-028X.JFP-14-505

Schlinkmann, K. M., Razum, O., & Werber, D. (2017). Characteristics of foodborne outbreaks in which use of analytical epidemiological studies contributed to identification of suspected vehicles, European Union, 2007 to 2011. In *Epidemiology and Infection* (Vol. 145, Issue 6, pp. 1231–1238). Cambridge University Press. https://doi.org/10.1017/S0950268816003344

Tack, D. M., Ray, L., Griffin, P. M., Cieslak, P. R., Dunn, J., Rissman, T., Jervis, R., Lathrop, S., Muse, A., Duwell, M., Smith, K., Tobin-D'angelo, M., Vugia, D. J., Kufel, J. Z., Wolpert, B. J., Tauxe, R., & Payne, D. C. (2020). *Preliminary Incidence and Trends of Infections with Pathogens Transmitted Commonly Through Food — Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 2016–2019*. *69*(17), 509–514. https://www.cdc.gov/mmwr/mmwr_continuingEducation.html

Wikswo, M. E., Roberts, V., Marsh, Z., Manikonda, K., Gleason, B., Kambhampati, A., Mattison, C., Calderwood, L., Balachandran, N., Cardemil, C., & Hall, A. J. (2021). Enteric illness outbreaks reported through the National Outbreak Reporting System, United States, 2009–19. *Clinical Infectious Diseases*, 1–8. https://doi.org/10.1093/cid/ciab771

TABLES & FIGURES

Figure 1: 2009 – 2019 Colorado single-state foodborne disease outbreak selection, NORS dataset

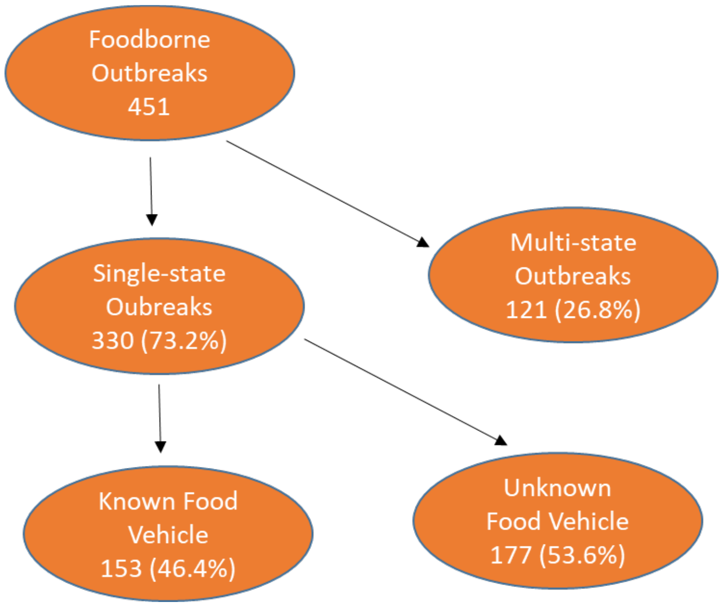

Table 1: Characteristics of foodborne, single state Colorado outbreaks, 2009 – 2019

Total Number of Outbreaks		**n = 330**
Pathogen (n, %)		
Norovirus	111	33.6%
Unknown	86	26.1%
Bacterial Toxin	53	16.1%
Salmonella	33	10.0%
Other	16	4.8%
Campylobacter	14	4.2%
O157	8	80.0%
Non O157	2	20.0%
Other Viral	3	0.9%
Parasite	2	0.6%
Shigella	1	0.3%
Listeria	1	0.3%
Outbreak Status (n, %)		
Food Vehicle Known	153	46.4%
Food Vehicle Unknown	177	53.6%
Agency that Led the Outbreak (n, %)		
CDPHE	35	10.6%
LPHA	295	89.4%
Detection Method (n, %)		
Complaint Based	275	83.3%
Pathogen Surveillance	55	16.7%
Sex (%)		
Average Percent Female		50.4%
Average Percent Male		44.0%
Average Percent Unknown		5.6%
Age Group (%)		
Average Percent Pediatric Cases		10.2%
Average Percent Adult Cases		61.7%
Average Percent Senior Cases		4.3%
Average Percent Unknown Cases		23.8%
Investigation Method (n, %)		
Routine Investigation Only	156	47.3%
Analytic Study	145	43.9%
Other Method	29	8.8%
Geographical Region (n, %)		
Number Multi Jurisdiction Outbreaks	16	4.8%
Number Single Jurisdiction Outbreaks	314	95.2%
Number FoodNET County Outbreaks	109	34.7%

Table 2: Characteristics of outbreaks between those with known food vehicle and outbreaks with unknown food vehicle

Total Number of Outbreaks					**n = 330**
Characteristic	Food Vehicle Known n = 153 (46.4%)		Food Vehicle Unknown n = 177 (53.6%)		*p*-value
Pathogen					
Norovirus	31	20.3%	80	45.2%	<.0001
Bacterial Toxin	35	22.9%	18	10.2%	
Bacterial	38	24.8%	21	11.9%	
Other	16	10.5%	5	2.8%	
Unknown	33	21.6%	53	29.9%	
Case Count (per outbreak)					
Mean Case Count	16.4	±22.1	12.1	±13.7	0.0366
Median Case Count	8		6		
No. Outbreaks ≥ 5 cases §	93	60.8%	101	57.1%	0.0283
Agency that led the outbreak					
CDPHE	27	17.6%	8	4.5%	0.0001
LPHA*	126	82.4%	169	95.5%	
Age Group					
No. Outbreaks >25% Pediatric Cases	30	9.1%	2	7.3%	0.1386
No Outbreaks > 25% Senior Cases	7	2.1%	13	3.9%	0.2931
Hospitalized Cases (per outbreak)					
Mean hospitalized cases	0.8	±3.5	0.2	±0.6	0.0230
Mean percent hospitalized cases	8.3%	±20.9%	3.5%	±13.4%	0.0169
No. Outbreaks with hospitalization data	147	96.1%	169	95.5%	0.7880
Investigation Method					
Routine Investigation	66	4.1.%	90	50.8%	0.0533
Analytic Study	78	51.0%	67	37.9%	0.0166
Other Method	9	5.9%	20	11.3%	0.0830
Setting					
Retail Food Establishments	78	51.0%	118	66.7%	0.0027
Private Residences	35	22.9%	22	12.4%	
Other	20	13.1%	12	6.8%	
Institutions	15	9.8%	24	13.6%	
Unknown	5	3.3%	1	0.6%	
Human Specimen Collection					
No. Outbreaks with Specimen Collection	107	69.9%	116	65.5%	0.3947
Total No. Specimen Collected	497			467	
Mean No. Specimen Collected	4.6	±7.1	4.0	±8.5	0.5539
No. outbreaks ≥ 2 specimen collected	77	72.0%	93	80.2%	0.4441

No. Outbreaks Missing Specimen Collection	46	30.1%	61	34.5%	
Number Primary Lab Confirmed Cases					
No. Outbreaks with lab confirmed cases	136	88.9%	158	89.3%	
Mean No. Lab Confirmed Cases	3.3	±6.5	1.3	±2.2	0.0010
No. Outbreaks Missing Primary Lab Confirmed Cases	17	11.1%	19	10.7%	
Geographical Region					
No. Multi-County Outbreaks	13	8.5%	3	1.7%	0.0041
No Single-County FoodNET Outbreaks	49	32.0%	60	33.9%	0.9238
No. Single-County non-FoodNET Outbreaks	91	59.5%	114	64.4%	

* LPHA = local public health agency, § = Number

Table 3: Characteristics of outbreaks between those with known food vehicle and outbreaks with unknown food vehicle, complaint-based detection

Total Number of Outbreaks					**n = 275**
Characteristic	Food Vehicle Known n = 116 (42.2%)		Food Vehicle Unknown n = 159 (57.8%)		*p*-value
Pathogen					
Norovirus	31	26.7%	80	50.3%	<.0001
Bacterial Toxin	34	29.3%	18	11.3%	
Bacterial	9	7.8%	5	3.1%	
Other	9	7.8%	3	1.9%	
Unknown	33	28.4%	53	33.3%	
Case Count (per outbreak)					
Mean Case Count	16.4	±19.4	12.1	±14.2	0.1020
Median Case Count	9		7		
No. Outbreaks ≥ 5 cases§	75	64.7%	96	60.4%	0.1112
Agency that led the outbreak					
CDPHE	10	8.6%	6	3.8%	0.0899
LPHA*	106	91.4%	153	96.2%	
Age Group					
No. Outbreaks >25% Pediatric Cases	19	6.9%	20	7.3%	0.3723
No Outbreaks > 25% Senior Cases	6	2.2%	12	4.4%	0.4317
Hospitalized Cases (per outbreak)					
Mean hospitalized cases	0.3	±0.9	0.1	±0.5	0.0217
Mean percent hospitalized cases	5.2%	±15.3%	1.4%	±7.1%	0.0136
No. Outbreaks with hospitalization data	110	94.8%	152	95.6%	0.78.7
Investigation Method					
Routine Investigation	49	42.2%	83	52.2%	0.0326
Analytic Study	60	51.7%	59	37.1%	0.0157
Other Method	7	6.0%	17	10.7%	0.1766
Setting					
Retail Food Establishments	57	49.4%	103	64.8%	0.0140
Private Residences	24	20.7%	20	12.6%	
Other	18	15.5%	11	6.9%	
Institutions	14	12.1%	24	15.1%	
Unknown	3	2.6%	1	0.6%	
Human Specimen Collection					
No. Outbreaks with Specimen Collection	72	62.1%	99	62.3%	0.9737
Total No. Specimen Collected	204			297	
Mean No. Specimen Collected	2.8	±1.9	3.0	±3.0	0.6567
No. outbreaks ≥ 2 specimen collected	72	100.0%	53	53.5%	0.8976

No. Outbreaks Missing Specimen Collection	44	37.9%	60	37.7%	
Number Primary Lab Confirmed Cases					
No. Outbreaks with lab confirmed cases	100	86.2%	140	88.1%	
Mean No. Lab Confirmed Cases	1.6	±2.4	1.1	±1.8	0.0586
No. Outbreaks Missing Primary Lab Confirmed Cases	16	13.8%	19	11.9%	
Geographical Region					
No. Multi-County Outbreaks	6	5.2%	3	1.9%	0.1304
No Single-County FoodNET Outbreaks	36	31.0%	53	33.3%	0.8319
No. Single-County non-FoodNET Outbreaks	74	63.8%	103	64.8%	

* LPHA = local public health agency, § = Number

Table 4: Characteristics of outbreaks between those with known food vehicle and outbreaks with unknown food vehicle, complaint-based detection

Total Number of Outbreaks					**n = 55**
Characteristic	Food Vehicle Known n = 37 (67.3%)		Food Vehicle Unknown n = 18 (32.7%)		*p*-value
Pathogen					
Norovirus	0	0.0%	0	0.0%	0.5766
Bacterial Toxin	1	2.7%	0	0.0%	
Bacterial	29	78.4%	16	88.9%	
Other	7	18.9%	2	11.1%	
Unknown	0	0.0%	0	0.0%	
Case Count (per outbreak)					
Mean Case Count	16.7	±29.4	5.3	±4.3	0.0268
Median Case Count	4		4.5		
No. Outbreaks ≥ 5 cases[§]	18	48.6%	5	27.8%	0.0296
Agency that led the outbreak					
CDPHE	17	45.9%	2	11.1%	0.0108
LPHA[*]	20	54.1%	16	88.9%	
Age Group					
No. Outbreaks >25% Pediatric Cases	11	20.0%	26	47.3%	0.5575
No Outbreaks > 25% Senior Cases	1	1.8%	36	65.5%	0.5959
Hospitalized Cases (per outbreak)					
Mean hospitalized cases	2.4	±6.7	0.7	±0.9	0.1362
Mean percent hospitalized cases	17.8%	±31.2%	22.2%	±31.3%	0.6233
No. Outbreaks with hospitalization data	37	100.0%	17	94.4%	0.3625
Investigation Method					
Routine Investigation	17	45.9%	7	38.9%	0.9251
Analytic Study	18	48.6%	8	44.4%	0.7695
Other Method	2	5.4%	3	16.7%	0.1728
Setting					
Retail Food Establishments	21	56.8%	15	83.3%	0.3375
Private Residences	11	29.7%	2	11.1%	
Other	2	5.4%	1	5.6%	
Institutions	1	2.7%	0	0.0%	
Unknown	2	5.4%	0	0.0%	
Human Specimen Collection					
No. Outbreaks with Specimen Collection	35	94.6%	17	94.4%	0.9816
Total No. Specimen Collected	293			170	
Mean No. Specimen Collected	8.4	±11.3	10.0	±20.5	0.7627
No. outbreaks ≥ 2 specimen collected	31	88.6%	14	82.4%	0.5377

No. Outbreaks Missing Specimen Collection	2	5.4%	1	5.6%	
Number Primary Lab Confirmed Cases					
No. Outbreaks with lab confirmed cases	36	97.3%	18	100.0%	
Mean No. Lab Confirmed Cases	8.1	±10.7	3.7	±3.4	0.0970
No. Outbreaks Missing Primary Lab Confirmed Cases	16	43.2%	0	0.0%	
Geographical Region					
No. Multi-County Outbreaks	7	18.9%	0	0.0%	0.0482
No Single-County FoodNET Outbreaks	13	35.1%	7	38.9%	0.7624
No. Single-County non-FoodNET Outbreaks	17	45.9%	11	61.1%	

* LPHA = local public health agency, § = Number

Table 5: Odds ratios of an outbreaks with a known food vehicle versus outbreaks with an unknown food vehicle

Characteristic	**OR (95% CI)**	***p*-value**
Pathogen		
Norovirus	1.0	
Bacterial	3.44 (1.52-7.78)	0.0031
Bacterial Toxin	5.97 (2.80-12.73)	<.0001
Other	10.87 (3.41-34.69)	<.0001
Unknown	1.84 (0.96-3.51)	0.0645
Setting		
Retail Food Establishment	1.0	
Private Residence	2.17 (1.09-4.30)	0.0266
Institution	0.54 (0.23-1.25)	0.1494
Other	2.07 (0.89-4.80)	0.0911
Unknown	3.64 (0.38-35.38)	0.2648
Case Count per Outbreak	1.02 (1.00 – 1.04)	0.0352
CDPHE Led Outbreak Investigation	2.99 (1.14-7.89)	0.0265
Analytic Study Conducted	1.55 (0.91-2.62)	0.1061
Percent Cases Hospitalized	1.00 (0.99-1.02)	0.6743