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Quantitative exposure model for the transmission of norovirus in retail food preparation

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ABSTRACT

It is widely recognized that the human noroviruses (HuNoV) are responsible for a large proportion of the world's foodborne disease burden. These viruses are transmitted by human fecal contamination and frequently make their way into foods because of poor personal hygiene of infected food handlers. This paper describes a probabilistic exposure assessment which models the dynamics of the transmission of HuNoV in the retail food preparation environment. Key inputs included degree of fecal shedding, hand hygiene behaviors, efficacy of virus removal and/or inactivation, and transferability of virus between surfaces. The model has a temporal dimension allowing contamination to be estimated as a function of time over the simulation period. Sensitivity and what-if scenario analyses were applied to identify the most important model inputs and evaluate potential mitigation strategies. The key inputs affecting estimates of the number of infectious viruses present in contaminated food servings, given the current model structure and assumptions, were as follows: mass of feces on hands (m_{FH}), concentration of virus in feces (nv_{CF}), number of bathroom visits, degree of gloving compliance (p_{WG}), hand-washing efficiency (HW_{eff}), and hand-washing compliance (p_{HW}). The model suggests that gloving and hand-washing compliance are most effective in controlling contamination of food products when practiced simultaneously. Moreover, the bathroom environment was identified as a major reservoir of HuNoV, even in the absence of an ill individual on site. This mathematical approach to modeling the transmission of gastrointestinal viruses should facilitate comparison of potential mitigations aimed at reducing the transmission of foodborne viruses.

1. Introduction

Acute viral gastroenteritis remains one of the most prevalent infections worldwide. Although caused by members belonging to a variety of virus families, the human noroviruses (HuNoV) (*Caliciviridea* family) have received increasing attention over the last few decades. The HuNoV are transmitted by the fecal–oral route through contact with human fecal material; they can also be shed in vomitus. Based on these two definitive sources, specific transmission of the HuNoV can occur directly between individuals or indirectly via consumption of contaminated food or water, or contact with fomites (Koopmans and Duizer, 2004). The relative importance of each of these routes is debated but it is widely recognized that the HuNoV group alone is responsible for a large proportion of the foodborne disease burden in the U.S. and Europe (Mead et al., 1999; Widdowson et al., 2005; Lopman et al., 2003).

Three types of foods are most often associated with sporadic cases and outbreaks of viral gastroenteritis, i.e., (i) molluscan shellfish contaminated during production; (ii) fresh produce items contaminated during production, harvesting, or packing; and (iii) prepared or ready-to-eat (RTE) foods contaminated during preparation. Poor personal hygiene practices of infected food handlers is the source of contamination for prepared foods, which is the product category most often implicated in HuNoV outbreaks (Bean et al., 1997). The risk of contamination posed by infected food handlers depends on many factors, including phase of clinical infection which impacts degree of virus shedding, personal hygiene habits, efficacy of virus removal and/or inactivation, ease of virus transfer, virus persistence, and a variety of behavioral factors. Clearly, contaminated hands and to a lesser degree, contaminated surfaces, play critical roles, acting as virus donors and recipients.

Quantitative microbial risk assessment (QMRA) has been widely used to characterize foodborne disease risks associated with bacterial pathogens such as *Salmonella* species, *Listeria monocytogenes*, and *Escherichia coli* O157:H7 Jaykus et al. (CAST, 2006). Some of these previous QMRA efforts have sought to model cross-contamination in the domestic setting (Christensen et al., 2005; Kusumaningrum et al., 2004; Rosenquist et al., 2003), while in industrial settings, modeling efforts have focused on environmental contamination with *L. monocytogenes* (Ivanek et al., 2004; Schaffner, 2004) and cross-contamination with *Salmonella* and *Campylobacter* (Nauta et al., 2005; Rosenquist

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et al., 2003; Yang et al., 2002; Van der Fels-Klerx et al., 2005). To date, there has been no focused attempt to apply quantitative models to the transmission or risk associated with foodborne gastrointestinal viruses. The most relevant related work is that of Michaels et al. (2004) who provided a QMRA framework to model hygiene practices in the retail food sector, but this work was not specific to HuNoV transmission.

In this study, we report the development of an exposure model which characterizes the dynamics of foodborne transmission of HuNoV in the retail food preparation environment. Sensitivity analysis was used to identify model parameters (inputs) providing the greatest contribution to the risk of virus contamination of prepared foods, while what-if scenario analyses were applied to evaluate the relative efficacy of potential control strategies to reduce the likelihood of contamination during food preparation.

2. Materials and methods

2.1. Overview of the model

The model was conceptualized in accordance with the personal hygiene risk management triad described by Michaels et al. (2004), which is based on the inter-relationship between cross-contamination (affected by the source of the contaminant during food handling) and hygienic efficiency and compliance (both of which are considered control measures). The general modeling approach is similar to that applied by the United States Environmental Protection Agency in their effort to model exposure of children to toxic residues on playsets and decks in which time–location–activity diaries for different individuals were modeled to simulate daily exposure values (Zartarian et al., 2006). However, in this case, we modeled the transmission dynamics of HuNoV among food products, food contact surfaces, employees' hands (gloves), and the restroom environment for a retail food preparation establishment with a selected number of employees working during an 8 hour shift.

The overall structure of the model is diagrammed in Fig. 1. At any point in time (t), food products, food contact surfaces, hands, and/or gloves are distributed among the compartments of HuNoV-contaminated and non-contaminated units. Because fecal contamination and vomiting are most likely to occur in the restroom environment, this was assumed to be the major reservoir for HuNoV contamination. Two sources of contamination were considered in the restroom area, i.e., personal (feces) and environmental (arising from contact with fecal matter or vomitus on surfaces such as sinks and toilets).

We assumed that five employees were present during a working shift in our conceptual retail food preparation establishment. Among these employees, we assumed that at least one was infected and

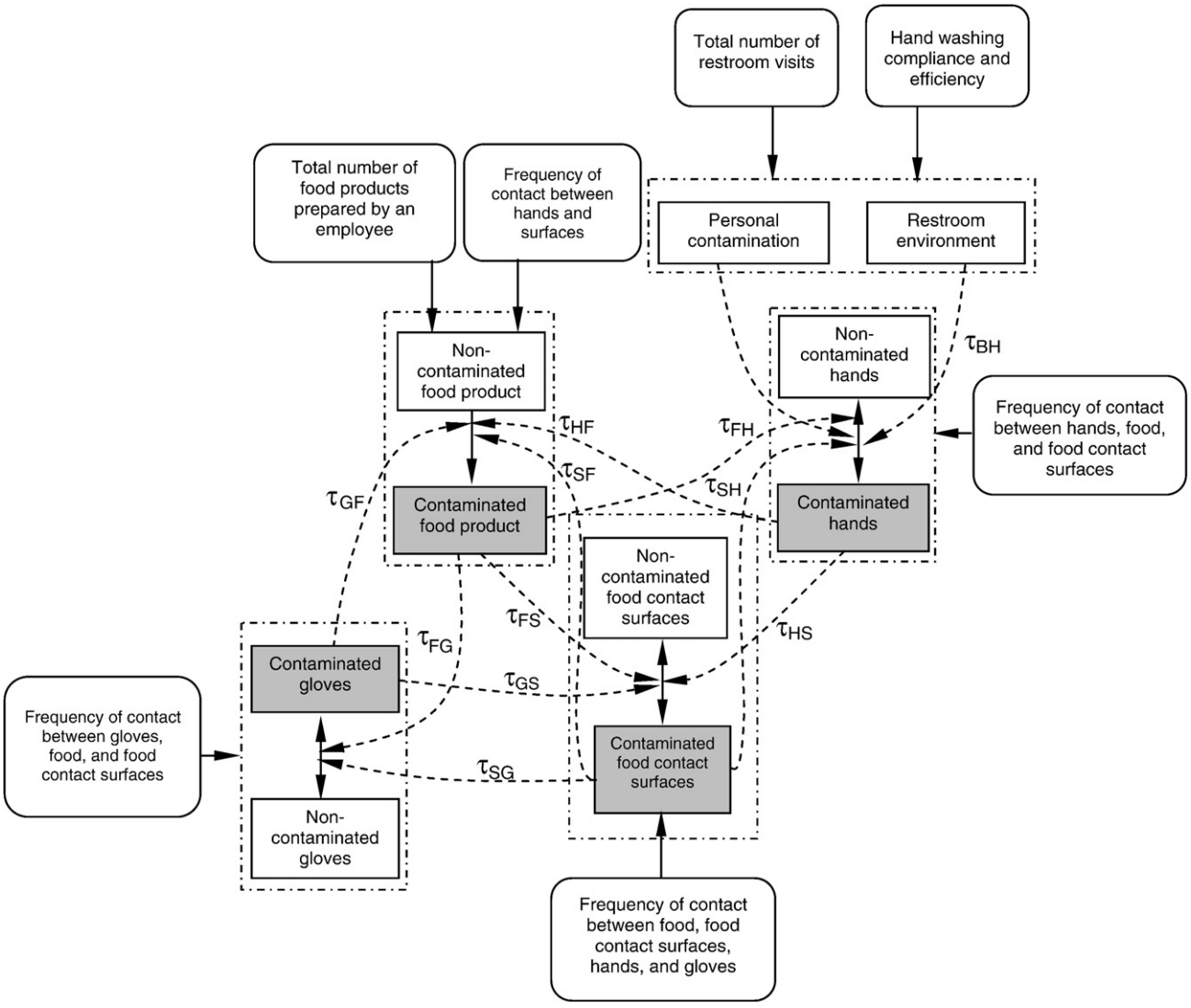

Fig. 1. Model overview. Solid lines represent transmission (change of contamination status from non-contaminated to contaminated), while dashed lines represent influences on these transmissions. τ_{ij} represents transfer rate between sources i and j, where i and j are selected among food products (F), gloves (G), hands (H), and food contact surfaces (S).