Effects of Cleaning Procedures on Indoor Microbial Aerosol Concentrations in Norovirus-Related Vomiting Contamination Events

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Abstract: Vomiting is a common acute event associated with norovirus infection and other acute gastrointestinal diseases and may result in a high biological contamination load in indoor environments. Previous studies have shown that routine activities, such as walking and vacuum cleaning, can induce the resuspension of deposited particles; however, experimental evidence regarding the impact of cleaning processes on airborne microbial aerosol levels under vomiting contamination scenarios remains limited. In this study, simulated vomiting experiments were conducted in a real office environment using a biosafe microbial tracer. Indoor airborne microbial aerosol concentrations were measured before cleaning after vomiting, during the cleaning process, and for several hours following the completion of cleaning. The results indicated that vomiting events could markedly increase airborne microbial aerosol levels within a short period. During cleaning, airborne microbial concentrations increased by approximately 54% compared with pre-cleaning levels. Under natural ventilation conditions, airborne microbial aerosol concentrations remained higher than pre-cleaning levels even 3 h after the completion of cleaning. These findings suggest that, under vomiting contamination scenarios, cleaning activities may temporarily increase exposure to airborne microbial aerosols.

Keywords: Vomiting contamination; Cleaning process; Airborne transmission; Microbial aerosols; Indoor environment

1. Introduction

Norovirus is one of the leading causative agents of acute gastroenteritis worldwide [1-2] and has frequently been associated with outbreak events in indoor settings such as restaurants, schools, and healthcare facilities [3-4]. Vomiting, a typical symptom of norovirus infection, is characterized by its sudden onset and high contamination load and has been identified by multiple epidemiological investigations as a critical trigger for environmental contamination and subsequent transmission [5].

Previous studies have demonstrated that droplets and aerosols generated during vomiting can carry large quantities of pathogens [6] and remain suspended in indoor air for a certain period, thereby posing inhalation exposure risks. Related findings indicate that vomiting events can cause a rapid and substantial increase in airborne pathogen concentrations and are closely associated with the occurrence of subsequent cases [7-8]. However, existing research has largely focused on the

instantaneous release phase of vomiting events, with limited attention paid to post-vomiting environmental management processes, particularly the effects of cleaning activities on changes in airborne contamination.

In indoor environment studies, human activities such as walking and vacuum cleaning have been recognized as common causes of particle resuspension [9], potentially leading to short-term increases in airborne particulate matter concentrations. Nevertheless, most of these studies have focused on routine cleaning scenarios and have not examined sudden contamination events characterized by a high biological load, such as vomiting incidents.

Therefore, following a vomiting event, it remains unclear whether cleaning activities can immediately reduce airborne exposure risks or whether they may instead exacerbate airborne microbial contamination in the short term, due to the lack of experimental evidence. In this study, a real office environment was selected as the experimental setting, and vomiting events were considered a high biological load contamination scenario. The study focuses on the temporal variation in indoor airborne microbial aerosol levels during subsequent cleaning processes, with the aim of providing experimental evidence to inform environmental management and risk control strategies following vomiting events.

2. Methods

2.1 Experimental Environment and Vomiting Scenario Setup

The experiment was conducted in a graduate student office at a university in Beijing, China. During the experimental period, the room remained under normal daily use conditions, and natural ventilation was maintained by partially opening the windows. The indoor air exchange rate during the experiments was determined to be approximately 1.39 h^{-1} using the carbon dioxide decay method.

A laboratory-developed vomiting simulation device was used to reproduce a short-duration vomiting contamination event. The simulation was performed under controlled conditions with a fixed release height (mouth height of 1.0 m above the floor) and direction (head tilted downward at an angle of 60°). The released volume (800 mL) and vomiting duration (3 s) were set within the ranges commonly reported for human vomiting events in the literature [10-11]. The present study did not aim to investigate the mechanisms of aerosol generation during vomiting; instead, the vomiting process was treated as a controllable contamination source to examine changes in airborne microbial aerosols during subsequent cleaning activities.

2.2 Tracer Microorganism and Cleaning Procedure

The artificial vomitus was prepared using sterile deionized water and a viscosity modifier (sodium carboxymethyl cellulose powder) to simulate the physical properties of real vomitus. Lactobacillus delbrueckii subsp. bulgaricus (CICC 6103) was added as a microbial tracer, as described in previous studies [12].

Following the completion of the vomiting simulation, the visibly contaminated area was manually cleaned. The cleaning procedure involved covering and removing the contamination using paper towels, followed by floor cleaning with a broom, dustpan, and mop. No chemical disinfectants were applied during the cleaning process, which lasted approximately 9 min in total.

2.3 Air Sampling and Microbial Analysis

Air samples were collected during three stages (Figure 1): (1) after the completion of vomiting

and before the initiation of cleaning; (2) during the cleaning process; and (3) 3 h after the completion of cleaning. Air sampling was performed using a liquid impingement sampler operated at a flow rate of 15 L·min^{-1}. The collection medium consisted of phosphate-buffered saline supplemented with 1% Tween 80.

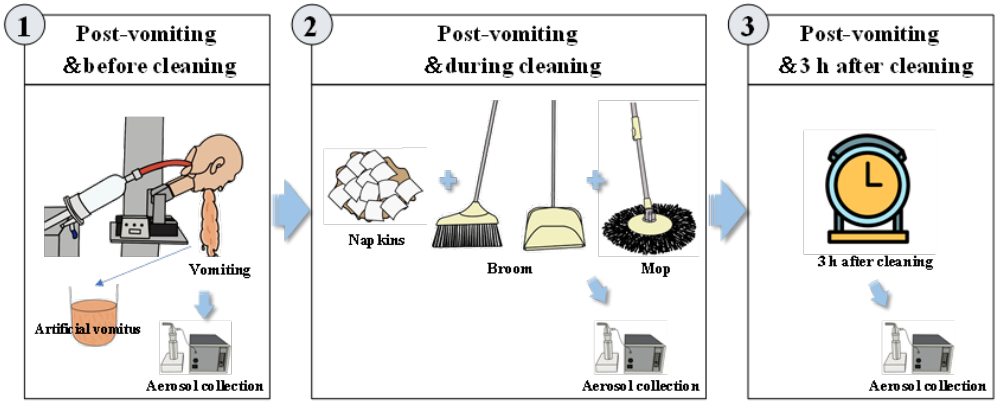

Figure 1: Schematic Diagram of the Air Sample Collection Stage.

The collected samples were analyzed using quantitative real-time polymerase chain reaction (qPCR). Quantification was performed with primers specific to L. delbrueckii subsp. bulgaricus [12]. Airborne microbial aerosol concentrations were expressed as gene copy numbers (copies/m^3).

3. Results

3.1 Variation in Airborne Microbial Aerosol Concentrations at Different Stages

No tracer microorganisms were detected in the air samples collected prior to the experiments, indicating the absence of detectable background contamination in the experimental environment (Table 1). After the completion of the vomiting simulation and before the initiation of cleaning, the airborne tracer concentration increased to 687.8 copies/m^3, demonstrating that a vomiting event can release detectable levels of microbial aerosols into indoor air within a short period.

Table 1: Concentration of Tracer Bacterium in Air at Different Experimental Stages.

Stage		Sampling duration (min)	Concentration of tracer bacterium (copies/m^3)
Before experiment		20	0
Post-vomiting	before cleaning	20	687.8
	during cleaning	9	1060.0
	3 h after cleaning	20	1160.2

During the cleaning process, the airborne tracer concentration increased further to 1060.0 copies/m^3, representing an approximately 54% increase compared with the pre-cleaning level. At this stage, airborne microbial aerosol concentrations reached relatively high levels over the entire experimental period.

In the air samples collected 3 h after the completion of cleaning, the airborne tracer concentration remained at 1160.2 copies/m^3, which was higher than the level measured before cleaning. Despite the

maintenance of natural ventilation during the experiment, no pronounced decay in airborne microbial aerosol concentrations was observed over this time scale.

3.2 Characteristics of Changes in Airborne Microbial Aerosols Before and After Cleaning

Comparisons across different stages showed that temporal changes in airborne microbial aerosol concentrations did not follow a simple monotonic decline. Relative to the initial phase following the vomiting event, airborne microbial aerosol levels increased markedly during the cleaning process and remained elevated for a period after cleaning.

Furthermore, airborne microbial aerosol concentrations detected in the post-cleaning stage were comparable to, or even slightly higher than, those observed during cleaning. These results indicate that, under the experimental conditions of this study, the completion of cleaning activities did not lead to the immediate removal of airborne contamination, and microbial aerosols could persist in indoor air following cleaning.

4. Discussion

The results of this study indicate that, under vomiting contamination scenarios, airborne microbial aerosol concentrations during cleaning were substantially higher than those measured prior to cleaning. This finding is consistent in trend with previous studies reporting that human activities such as walking and vacuum cleaning can induce particle resuspension [9], suggesting that mechanical disturbances generated during cleaning may promote the re-entrainment of microbe-laden particles deposited on floors or other surfaces into the air.

Several hours after the completion of cleaning, airborne microbial aerosol concentrations remained at relatively high levels. This observation may be attributed to multiple factors. On the one hand, resuspended particles generated during cleaning may exhibit prolonged residence times in indoor environments with limited ventilation. On the other hand, normal human activities following cleaning may continue to induce minor disturbances [13], thereby delaying the decay of airborne microbial aerosols. It should be noted that the natural ventilation conditions applied in this study contributed, to some extent, to the dilution of indoor air contaminants; however, within the experimental time scale, their effectiveness in removing microbial aerosols was limited. These findings suggest that, in similar office environments, reliance on natural ventilation alone may be insufficient to rapidly eliminate vomiting-related airborne microbial contamination.

From a practical management perspective, existing emergency response guidelines for vomiting events typically emphasize the prompt removal of visible contamination and surface disinfection, while relatively little attention is given to potential airborne exposure during the cleaning process. The results of this study suggest that, when feasible, enhanced ventilation prior to or during cleaning, as well as the use of appropriate personal protective measures, should be considered to reduce inhalation exposure risks for cleaning personnel and nearby occupants [14].

This study has several limitations. First, the experiments were conducted in a single office environment, and the results may be influenced by specific spatial layouts, ventilation conditions, and patterns of occupant activity. Further investigations are needed to assess the behavior of airborne microbial aerosols across different types of indoor environments. Second, a biosafe microbial tracer was used to quantify airborne microbial aerosols. Although the tracer reflects general trends in the behavior of microbial particles in air, it may differ from actual pathogens in terms of viability and infectivity. Finally, this study primarily focused on relative changes in airborne microbial aerosol

levels before and after cleaning and did not systematically compare the effectiveness of different cleaning methods or protective measures. These factors may limit the generalizability of the findings, highlighting the need for future studies incorporating multiple scenarios and conditions to further validate the results.

5. Conclusion

This study investigated the effects of cleaning processes on indoor airborne microbial aerosol levels in an office environment using simulated vomiting experiments. The results demonstrated that airborne microbial aerosol concentrations can increase transiently during cleaning and persist for a period after the completion of cleaning. These findings highlight the importance of considering potential airborne exposure risks associated with cleaning activities during the management of vomiting contamination events.

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