Cruise Ship Environmental Hygiene and the Risk of Norovirus Infection Outbreaks: An Objective Assessment of 56 Vessels over 3 Years

Philip C. Carling,1,2 Lou Ann Bruno-Murtha,3,4 and Jeffrey K. Griffiths5
1Carney Hospital, 2Boston University School of Medicine, 3Cambridge Health Alliance, 4Harvard Medical School, and 5Tufts University Schools of Medicine, Nutrition, and Engineering, Boston, Massachusetts

Background. Norovirus infection outbreaks (NoVOs) occur frequently in closed populations, such as cruise ship passengers. Environmental contamination is believed to play an important role in NoVO propagation.

Methods. Trained health care professionals covertly evaluated the thoroughness of disinfection cleaning (TDC) of 6 standardized objects (toilet seat, flush handle or button, toilet stall inner handhold, stall inner door handle, restroom inner door handle, and baby changing table surfaces) with high potential for fecal contamination in cruise ship public restrooms, by means of a previously validated novel targeting method.

Results. Fifty-six cruise ships (∼30% of 180 vessels operated by 9 large cruise lines) were evaluated from July 2005 through August 2008. Overall, 37% (range, 4%–100%; 95% confidence interval, 29.2%–45.4%) of 8344 objects in 273 randomly selected public restrooms were cleaned daily. The TDC did not differ by cruise line and did not correlate with the Centers for Disease Control and Prevention (CDC) Vessel Sanitation Program inspection scores ($r^2$, .002; $P = .75$). More than half the vessels had overall TDC scores <30%, although several of these low-scoring ships had near-perfect CDC sanitation scores. The mean TDC of the 3 ships evaluated within 4 months before a NoVO (10.3%) was substantially less than the mean TDC of the 40 ships that did not experience NoVOs (40.4%) ($P < .004$).

Conclusions. An objective evaluation of public restroom environmental hygiene on 56 cruise ships found that only 37% of selected toilet area objects were cleaned on a daily basis. Low TDC scores may predict subsequent NoVO-prone vessels. Enhanced public restroom cleaning may prevent or moderate NoVOs on cruise ships.

Outbreaks of acute gastroenteritis (AGE) often occur in closed populations, such as institutionalized persons or cruise ship passengers [1]. Recent epidemiologic investigations of outbreaks of AGE have confirmed that >95% of cruise ship AGE outbreaks are caused by norovirus (NoV) [2]. Despite biannual sanitation monitoring and despite hand hygiene interventions among passengers and crew members, 66 ships monitored by the United States Centers for Disease Control and Prevention (CDC) have experienced NoV infection outbreaks (NoVOs) since mid-2003. In addition, from 2002 through 2006, 43 cluster outbreaks of confirmed NoV infection occurred, often serially, on 13 European-based cruise ships [3]. Although the use of alcohol-based hand rub has been promoted by cruise lines to limit the spread of NoV [4], alcohol has limited effectiveness in killing calciviruses [5], suggesting this approach has limitations.

NoV survives on stainless steel surfaces for weeks at ambient temperatures [6], and NoV can be transmitted sequentially to ≥7 different surfaces [7]. The detection of outbreak strains of NoV on general environmental surfaces as well as on surfaces in restrooms during infection outbreaks on cruise ships [8], the serial occurrence on cruise ships of NoVOs caused by identical strains of NoV [8–11], and the results of cruise ship NoVO viral genetic sequencing collectively indicates that environmental contamination plays an important role in transmission [8–11]. Recent studies in health care settings [12] have documented opportunities to improve environmental disinfection cleaning of toilet area surfaces that are believed to play a role in the
transmission of enteric pathogens. In light of these considerations, we undertook a covert evaluation of environmental hygiene practices related to public restrooms on commercial cruise ships.

METHODS

The thoroughness of environmental disinfection cleaning (TDC) of public restrooms was evaluated in 56 large cruise ships that accommodate from 1258 to 3600 passengers, in a manner identical to that previously used to evaluate the TDC in acute care hospitals [12]. Each ship was covertly evaluated by a health care professional (38 nurses, 4 physicians, and 4 allied health professionals), each of whom was trained to evaluate TDC in a consistent manner. A transparent, easily cleanable, environmentally stable solution that dries on surfaces rapidly and fluoresces when exposed to ultraviolet light was used to evaluate the TDC. The disclosing agent consists of a mixture of several natural gluten-derived glues with mild detergents, such as those found in personal hygiene liquid soaps, to which a small amount of clear natural fluorescent dye is added. The material, which has the consistency of thick syrup, is dispensed on the targeted object with a nipple-tipped 30-mL plastic reagent bottle. Approximately 0.03 mL of material is applied to each test object, creating an ∼1.0-cm “target” that becomes inconspicuous as it dries over several minutes. It resists dry abrasion yet is easily removed with light abrasion after being moistened with water or a water-based disinfectant. The target is readily highlighted by a handheld ultraviolet light and remains easily removable for many months [12]. Six standardized objects were marked while the restroom was not being used. Each object was marked on a surface that was readily accessible to cleaning. Twenty-four hours later, each object was evaluated to determine whether the target had been removed. Any object that had been cleaned was remarked, and the restroom was reevaluated 24 hours later. Serial assessment of ≥5 restrooms, chosen for their diversity by the assessor, was performed for 5 to 7 days on each vessel. The first 5 standardized objects were chosen because of their high risk of becoming contaminated by fecal matter as a result of routine toileting activities (toilet seat, flush handle or button, toilet stall inner handhold, toilet stall inner door handle or latching device, and the baby changing table surface). A sixth standardized object, the restroom inner door handle or pull, was also evaluated, given its risk of being contaminated by enteric pathogens if hand hygiene was overlooked after toileting.

Instat 3.0 (Graph Pad Software) was used to compare continuous variables by means of Mann-Whitney U or unpaired t tests. Linear regression methods were used to determine whether there was a relationship between the TDC and other variables.

RESULTS

The convenience sample of 56 cruise ships was evaluated from July 2005 through August 2008. All ships belonged to large multivessel cruise lines and had participated in the CDC’s National Center for Environmental Health Vessel Sanitation Program (VSP) [2] for ≥4 years. Fifty-three ships were United States flagged, and 54 originated from US ports. From 1 to 15 ships from each of 9 cruise lines were evaluated, with 46 of the vessels (82%) belonging to the 5 largest cruise lines.

Overall, 37% (95% confidence interval [CI], 29.2%–45.4%) of 8344 objects in 273 randomly selected public restrooms that were evaluated on 1546 occasions were cleaned by serial daily observations. The overall TDC of the 6 standardized surfaces on each ship ranged from 4% to 100%. Although some objects in most restrooms were cleaned at least daily, on 275 occasions (18%) no objects in a restroom were cleaned for ≥24 hours. There was no recognizable trend in the TDC when ships were stratified by cruise line (Figure 1). No differences were detected between handicapped-accessible and general access restrooms (mean TDC, 43.5% vs 43.1%; P = .79). Cleaning of individual objects on different ships ranged 0%–100%. Although the overall best-cleaned object, the toilet seat (50%), was better cleaned than the least thoroughly cleaned object, the baby changing table (30%), the difference only just reached significance (P = .05). Furthermore, 19 objects in 13 ships were not cleaned at all during the 5- to 7-day monitoring period. Toilet area handholds were largely neglected, accounting for more than half of the uncleared objects on 11 ships. Although almost all standardized objects were assessed at the time of each evaluation, baby changing tables were not found in public restrooms on 79% of vessels. On 3 ships, none of the changing tables were cleaned during the study period. Regression analysis failed to show a correlation between vessel overall TDC and vessel size (r², 0.06; P = .1) [4] or mean passenger cost per person per day (r², 0.0003; P = .9) [4].

Serendipitously, 16 of the evaluated ships experienced 19 AGE outbreaks from 1 to 30 months before or after the TDC of public restrooms was monitored [13]. This natural experiment provided us with an opportunity to assess the relationship, if any, between TDC and AGE outbreaks. Although the mean TDC was less on the ships that had experienced AGE outbreaks than on the ships that had not (35.8% vs 40.4%), the difference was not statistically significant (P = .6). Six of the 19 outbreaks occurred within 12 months of the ship’s evaluation as part of this study (Figure 2). The overall TDC of the 3 ships inspected within the year before a NoVO (at 1 month, 1 month, and 4 months before a NoVO, respectively) disclosed the overall cleaning of these vessels to be 10%, 10%, and 11%, with a mean TDC of 10.3%, which was significantly less than the mean TDC of the 40 ships that had not experienced AGE outbreaks (40.4%) (P < .004). Conversely, the overall TDC of
the 3 ships evaluated within the year after a NoVO (at 1 month, 1 month, and 2 months after a NoVO, respectively) documented scores of 56%, 78%, and 92%, with a mean TDC of 75.3%, which was significantly higher than the mean TDC for the ships that had not experienced AGE outbreaks during the study period (40.4%) (P < .04). During the 3 years studied, the mean CDC VSP score closest to the month each ship was evaluated was 96.9 out of a possible 100 points (95% CI, 96.2–97.5 points). No significant relationship was found in regression analysis between the VSP scores and the documented TDC of potentially contaminated restroom surfaces (r², .002; P = .75).

DISCUSSION

Our major finding was that only 37% of 6 surfaces that had a high likelihood of being contaminated with enteric pathogens during routine toileting activities were cleaned at least once daily on 56 large cruise ships sampled during a 3-year period. Although the overall TDC ranged widely (4%–100%), it was ≥30% on more than half of the ships evaluated. These findings are of particular note because 5 of the 6 evaluated objects could readily be directly contaminated by enteric pathogens during regular use. Although hand hygiene with soap after toileting may diminish the transmission of enteric pathogens via bathroom door knobs or pulls, hand washing is unlikely to mitigate the potential for any of the other toilet area contact surfaces to serve as a source of transmission of enteric pathogens. Furthermore, there was a substantial potential for washed hands to become contaminated while the passenger was exiting the restroom, given that only 35% of restroom exit knobs or pulls were cleaned daily. Consequently, only disinfection cleaning by
cruise ship staff can reasonably be expected to mitigate these risks. Young children experience AGE frequently and shed NoV before symptomatic illness [14]. Asymptomatic children shed environmentally resilient [6] NoV for \( \leq 100 \) days after infection [14, 13]. Thus, the likelihood of baby changing tables being fecally contaminated with NoV is high (there are \( 1 \times 10^7–1 \times 10^{12} \) virions/g feces [15]). Because recent data suggest that a single NoV virion can transmit infection [16], it is of particular concern that only 30% of changing tables were cleaned on a daily basis, with none being cleaned during 5 to 7 days of observation on 3 (25%) of the 12 equipped ships.

Six ships were serendipitously evaluated within 4 months of experiencing NoVOs, 3 before and 3 after [17]. The overall mean TDC for the 3 ships that were inspected 1 month, 1 month, and 4 months before a NoVO, respectively, was 10.3%, significantly lower than the mean TDC for the 40 ships that did not experience AGE outbreaks during the study (40.4%) \((P < .004)\) (Figure 2). In contrast, the mean TDC of the 3 ships evaluated within 2 months after a NoVO was 75.3%, significantly higher than the mean TDC of the nonoutbreak ships (40.4%) \((P < .04)\) (Figure 2). Although the conclusions that can be drawn from these observations are limited by our study design and by the small number of vessels that by chance were evaluated in proximity to a NoVO, the findings are consistent with the possibility that poor restroom cleaning contributes to NoVOs on cruise ships and that environmental hygiene is typically enhanced immediately after an outbreak.

Since 1975, the CDC has had an inspection and remediation program designed to “prevent and control the introduction, transmission and spread of gastrointestinal illness on cruise ships” [18]. The VSP uses VSP Operations Manual guidelines [19] and involves unannounced biannual inspections of all US cruise ships that carry \( > 13 \) passengers and all vessels that have a foreign itinerary with US ports. Inspections include “hotel accommodations: for routine cleaning sequences and infection control procedures during outbreaks of gastrointestinal illness, including the use of appropriate disinfectants and outbreak policies” [18]. Ships are scored on a 100-point scale, and a score \(< 85\) is considered to be failing. All inspection scores as well as remediation interventions are posted on the CDC Web site [20]. Although the implementation of the VSP and a resultant significant increase in ship sanitation scores were historically associated with a reduction in the number of outbreaks [21], there does not appear to be any current relationship between VSP scores and the number of NoVOs.

From July 2005 through August 2008, a total of 66 AGE outbreaks involving \( \geq 9031 \) passengers and crew on 47 different ships were investigated by the CDC [17]. NoV was identified as the causative agent in 57 (97%) of the 59 outbreaks for which a pathogen was identified. The mean VSP score that was documented closest to the AGE outbreak for the 50 ships inspected within a year of the outbreak was 97.2/100 points (95% CI, 96.3–97.9 points). This mean score was actually significantly higher than the mean score for 132 ships inspected during the same time that had not experienced AGE outbreaks (95.2/100 points; \( P = .03 \)) [20]. Consistent with this data, our findings suggest that the VSP inspection criteria have a low sensitivity for identifying shortcomings in actual public restroom environmental hygiene practice. Furthermore, the VSP Operations Manual mandates only that toilet and hand-washing facilities be “convenient and accessible in design and installation” (3/100 points) and that there is “maintenance of hand cleanser, sanitary towels, waste receptacles, and hand washing signs” (1/100 points) [19, p. 189]. Although an update to the VSP manual recommends “cleaning and disinfecting all public areas, including handrails and restrooms, on a continuous basis until the proportion of cases decreases to \(< 2\%\)” during NoVOs (Standard 9.1.1.1.1) [19, p. 113], it does not mandate standards for routine hygiene practices for public restrooms, in particular before outbreaks, when the potential for prevention is greatest.

Although to our knowledge this report represents the first study of environmental hygiene on cruise ships, studies of high-risk object disinfection cleaning in toilet areas of acute

---

**Table 1. A Comparison Between the Thoroughness of Disinfectant Cleaning (TDC) of Toilet Area Objects in 273 Public Restrooms on 56 Cruise Ships and the TDC of 1294 Bathrooms in 36 Acute Care Hospitals**

<table>
<thead>
<tr>
<th>Object</th>
<th>On cruise ships</th>
<th>In hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. evaluated</td>
<td>No. cleaned</td>
</tr>
<tr>
<td>Toilet seat</td>
<td>2010</td>
<td>1011</td>
</tr>
<tr>
<td>Flush device</td>
<td>1816</td>
<td>763</td>
</tr>
<tr>
<td>Toilet stall door</td>
<td>1885</td>
<td>697</td>
</tr>
<tr>
<td>Bathroom door</td>
<td>1287</td>
<td>451</td>
</tr>
<tr>
<td>Handhold</td>
<td>1249</td>
<td>387</td>
</tr>
<tr>
<td>Baby changing table</td>
<td>107</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>8344</td>
<td>3112</td>
</tr>
</tbody>
</table>

**NOTE.** CI, confidence interval.
care hospitals by the Healthcare Environmental Hygiene Study Group have demonstrated similar results [12]. An evaluation of the TDC that occurs upon patient discharge comprised 4840 toilet area objects in 36 hospitals and used the identical method (Table 1); it disclosed an overall cleaning rate of 46.5% for toilet seats, flush handles, toilet area inner handholds, and toilet room doors (neither stall doors nor changing tables were available for evaluation in hospitals). This result was similar to our finding that 39.5% of these 4 objects were cleaned daily in cruise ship public restrooms. In acute care hospitals, educational and programmatic interventions along with serial performance feedback to the environmental services management and line staff led to improved discharge cleaning (from 48% at baseline to 77% following interventions; \( P < .001 \), without substantial added personnel resources [12]. In addition, Goodman and associates demonstrated that a programmatic approach identical to that used by the Healthcare Environmental Hygiene Study Group significantly reduced environmental contamination with methicillin-resistant \( \text{Staphylococcus aureus} \) and vancomycin-resistant \( \text{Enterococcus} \) in 10 intensive care units of a tertiary care referral hospital [22]. Further analysis of the intervention over time has confirmed decreased transmission of these pathogens to patients [23]. These results, along with those of similar studies [24–26], raise the possibility that similar objective, structured monitoring and process improvement interventions could improve cruise ship environmental hygiene. This study has several limitations. The use of 51 individuals to evaluate study ship TDC raises the possibility of observer variability. The standardized training of the observers, the intrinsically objective nature of the evaluation tool and process [12], and the similarity of the objects cleaned on cruise ships and in acute care hospitals suggest that observer bias did not significantly affect our findings. Although we used a covert convenience sampling strategy, we nonetheless sampled a diverse set of bathrooms on 30 (35%) of the 86 ships registered to the 9 cruise lines [27], suggesting that our results may be representative of the larger set of vessels. If so, broader evaluation of environmental hygiene on cruise ships may be warranted.

Although this investigation was not designed to investigate a causal relationship between the TDC of restrooms and the risk of a ship experiencing a NoVO, by chance our study documented statistically lower rates of environmental cleaning before AGE outbreaks and statistically higher rates of environmental cleaning after AGE outbreaks in a subsample of vessels, compared with the rates of environmental cleaning in ships without AGE outbreaks. Environmental contamination has been well documented during and after NoV infections in non-institutional [28], institutional [29–32], and cruise ship outbreaks [8]. Furthermore, Hejne and associates recently reported that the assignment of separate toilets for sick and well individuals and the cleaning of toilet surfaces with bleach decreased NoV transmission by 84.9% during an outbreak in the Netherlands [33]. Indeed, both the serial occurrence of NoVOs that was terminated only by enhanced environmental hygiene on the vessel [8–11] and biological plausibility provide strong support for the hypothesis that suboptimal environmental hygiene plays a role in the transmission and perpetuation of NoV infections. Our findings are consistent with this hypothesis.

A recent expert panel report of the European Center for Disease Prevention and Control (Stockholm, Sweden, September 2006) was issued in response to increasing numbers of NoVOs on European cruise ships. It concluded that “there is a need for a generic set of guidelines on basic hygienic principles to prevent and control NoV infections on cruise ships” [34]. Although historical data suggest that current VSP guidelines decrease the number of non-NoV infection outbreaks, more recent data suggest that environmental contamination is particularly relevant to NoV transmission. Thus, we believe that enhanced standards for ongoing monitoring and continual improvements in restroom cleaning could rationally be included in such guidelines.

In conclusion, only 37% of toilet surfaces at risk for pathogen contamination on 56 cruise ships were cleaned on a daily basis when objectively evaluated using a validated method. Substantial opportunities to improve the TDC were apparent on most of the surveyed vessels. Although the TDC was <30% on more than half of the ships, near-perfect cleaning was documented on several vessels, providing evidence that a high level of environmental hygiene is achievable. We believe that additional studies on the role of contaminated surfaces in cruise ship NoV transmission are warranted to determine whether improved environmental hygiene will decrease the incidence, duration, or severity of outbreaks. A number of studies have shown that programmatic improvement in disinfection cleaning in hospitals is achievable, raising the possibility that improving hygienic cleaning may be feasible and beneficial to passengers and crew members who are traveling on cruise ships [12, 22, 35, 36].

Acknowledgments

We gratefully acknowledge the healthcare professionals who gave generously of their time to collect the data upon which this report is based.


References

18. Centers for Disease Control and Prevention National Center for Environ-
17. Centers for Disease Control and Prevention National Center for Envi-
19. Centers for Disease Control and Prevention National Center for En-
13. Kirkwood CD, Streitberg R. Calicivirus shedding in children after re-
15. Rockx B, De Wit M, Vennema H, et al. Natural history of human ca-
10. Widdowson M, Cramer E, Hadley L, et al. Outbreaks of acute gastro-
8. Verhoef L, Boxman IL, Duizer E, et al. Multiple exposures during a
7. Barker J, Vipond IB, Bloomfield SF. Effects of cleaning and disinfection
5. Said MA, Perl TM, Sears CL. Gastrointestinal flu: norovirus in health-
3. Said MA, Perl TM, Sears CL. Gastrointestinal flu: norovirus in health-
2. Liu P, Wong E, Moe CL. Survival of norovirus, ms2 coliphage, and E 
coli on surfaces and in solution [abstract K-4142]. In: Program and
abstracts of the 46th annual meeting of the Infectious Diseases Society of
America (San Diego). 2008.


