What is the risk of acquiring SARS-CoV-2 from the use of public toilets?

Stephanie J. Dancer[a,b,*], Yuguo Li[c], Alwyn Hart[d], Julian W. Tang[e], Davey L. Jones[f,g]

[a]*Department of Microbiology, Hairmyres Hospital, NHS, Lanarkshire, G75 8RG, Scotland, UK*

[b]*School of Applied Sciences, Edinburgh Napier University, Edinburgh, EH14 1DJ, Scotland, UK*

[c]*Department of Mechanical Engineering, University of Hong Kong, Hong Kong, China*

[d]*Environment Agency, Research Assessment & Evaluation, Streetsbrook Road, Solihull, B91 1QT, West Midlands, England, UK*

[e]*Respiratory Sciences, University of Leicester, Leicester, LE1 7RH, England, UK*

[f]*Environment Centre Wales, Bangor University, Deiniol Road, Bangor, Gwynedd, LL57 2UW, Wales, UK*

[g]*UWA School of Agriculture and Environment, University of Western Australia, Perth, WA 6009, Australia*

[*]Corresponding author at: Department of Microbiology, Hairmyres Hospital, NHS, Lanarkshire, G75 8RG, Scotland, UK

E-mail address: stephanie.dancer@lanarkshire.scot.nhs.uk (S.J. Dancer)

Highlights

- Public toilets may act as a contact hub point for SARS-CoV-2 transmission.
- All accepted transmission mechanisms for SARS-CoV-2 co-exist in a public toilet.
- Faecal and urinary derived aerosols contain viable SARS-CoV-2 virus.
- Issues over space, ventilation, frequency of use, cleaning and maintenance compound the transmission risk.
- Actions to prevent COVID-19 infection are offered in lieu of supportive scientific evidence.

ABSTRACT

Public toilets and bathrooms may act as a contact hub point where community transmission of SARS-CoV-2 occurs between users. The mechanism of spread would arise through three mechanisms: inhalation of faecal and/or urinary aerosol from an individual shedding SARS-CoV-2; airborne transmission of respiratory aerosols between users face-to-face or during short periods after use; or from fomite transmission via frequent touch sites such as door handles, sink taps, lota or toilet roll dispenser. In this respect toilets could present a risk comparable with other high throughput enclosed spaces such as public transport and food retail outlets. They are often compact, inadequately ventilated, heavily used and subject to maintenance and cleaning issues. Factors such as these would compound the risks generated by toilet users incubating or symptomatic with SARS-CoV-2. Furthermore, toilets are important public infrastructure since they are vital for the maintenance of accessible, sustainable and comfortable urban spaces. Given the lack of studies on transmission through use of public toilets, comprehensive risk assessment relies upon the compilation of evidence gathered from parallel studies, including work performed in hospitals and prior work on related viruses. This narrative review examines the evidence suggestive of transmission risk through use of public toilets and concludes that such a risk cannot be lightly disregarded. A range of mitigating actions are suggested for both users of public toilets and those that are responsible for their design, maintenance and management.

Keywords: COVID-19; SARS-CoV-2; communal washroom; aerosol transmission, public health risk

1. Introduction

Bathrooms accommodating toilet facilities provide a route for all known transmission pathways of SARS-CoV-2 through exposure to air and surfaces. It is not unusual for public toilets to 'contain the highest density of people within the smallest amount of real estate' (Poland, 2020). Toilets in theatres, schools, restaurants, bars, shopping centres and sports facilities, in particular, may experience short periods of very heavy use. These facilities are considered important public infrastructure since they are vital for the maintenance of accessible, sustainable and comfortable urban spaces (Greed et al., 2004). Contamination through heavy use of toilets could present a far greater risk than indoor transmission in a public venue because there are additional risks from the production of urinary and faecal aerosol. Toilets illustrate a point in the sewage system at which the load of infective virus from faeces and urine are at their highest. It has already been established that coronaviruses can persist for long periods in water and sewage (Ahmed et al., 2020; Casanova et al., 2009) and contaminated water could be a potential vehicle for human exposure, particularly if aerosols are generated (Ahmed et al., 2020; Johnson et al., 2013). Indeed, monitoring wastewater for SARS-CoV-2 has already been explored to provide an early warning tool for community transmission (Cao and Francis, 2021; Foladori et al., 2020; Lodder and de Roda Husman, 2020; Medema et al., 2020).

Since few, if any, real life studies have yet been conducted on the SARS-CoV-2 transmission risk from public toilets, the possibility that these facilities could act as a transmission hub can only be explored by examining evidence for discrete statements relevant to toilet use (Fitzgerald et al., 2021). These encompass the usual sequence of stages for a toilet visit conditioned by human behaviour, alongside evidence for physical parameters such as viral RNA, survival, infectivity, people-traffic, room size, hand hygiene resources, cleaning practices and ventilation status. Infection risks from toilets have previously been determined using bacterial and viral markers, with prior epidemiological studies on other viruses strongly linked with contaminated excreta (Carling et al., 2009; Verani et al., 2014).

Tracing the source and mode of viral infections is notoriously difficult. In the case of common enteric (non-respiratory) viruses, such as norovirus, the faecal-oral and vomit-oral routes represent the primary infection pathways (Chan et al., 2006). However, the exact mode of transmission (e.g. aerosol vs. fomite) and person-to-person chain of infection for enteric viruses remains poorly understood in most disease outbreaks (Uchino et al., 2006; Xiao et al., 2017; Xiao et al., 2018). In the case of SARS-CoV-2, the potential to identify the mode of infection is made even harder due to possible simultaneous respiratory, faecal and urinary release of the virus. It is therefore virtually impossible to distinguish between faecal-oral and oral-oral routes of infection in a public toilet setting. In addition, unlike other viruses, SARS-CoV-2 infection may also occur via the ocular route (Qu et al., 2021), providing multiple infection points.

Despite the difficulty in tracking infections, there is preliminary evidence supporting the possibility of SARS-CoV-2 transmission through toilet use (Yun Chen et al., 2020; Gu et al., 2020; He et al., 2020; Wang W et al., 2020; Xiao et al., 2020a; Zhang et al., 2020a). Two studies have shown that the toilet was among the most contaminated areas in indoor settings (Ding et al., 2020; Ma et al., 2020): in one of these, a patient whose toilet air sample was positive had a negative exhaled breath sample, intimating that airborne SARS-CoV-2 in toilets could originate from faeces rather than air (Zhang and Duchaine, 2020). On June 29, 2020, the government of Beijing municipality reported two cases where two individuals were probably infected with SARS-CoV-2 after using a community public toilet (Sun and Han, 2020). Risks from faecal and urinary aerosol have been hypothesised based on virus presence and evidence from previous SARS outbreaks (Amirian, 2020; Bwire et al., 2020; Yifei Chen et al., 2020; Gupta et al., 2020; Jones D et al., 2020; Kang et al., 2020; Li et al., 2020; Liu et al., 2020; McDermott et al., 2020; Meng et al., 2020; Patel, 2020; Santos et al., 2020; Sun J et al., 2020; Wang W et al., 2020; Wong et al., 2020; Wu Y et al., 2020; Xu D et al., 2005; Xu Y et al., 2020). Using rRT-PCR testing, the overall prevalence of SARS-CoV-2 in faecal samples from patients with confirmed Covid-19 is 40% (Wong et al., 2020), with higher rates reported for patients presenting with gastrointestinal symptoms and patients with more severe disease (Wong et al., 2020; Zhang Y et al., 2020a). A systematic review found that rectal swabs were more likely to be positive for SARS-CoV-2 than sputum specimens (87.8% vs 68.1%) (Bwire et al., 2020).

These reports do not necessarily prove that infectious virions are present in faeces or that the virus has spread through faecal transmission (Amirion, 2020). However, viable virus has been isolated and confirmed from patient stool and urinary samples (Jeong et al., 2020; Jones D et al., 2020; Wong et al., 2020; Wang W et al., 2020; Xiao et al., 2020a; Xiao et al., 2020b; Zhang H et al., 2020; Zhang Y et al., 2020a; Zhang Y et al., 2020b). The ability of the virus to spread through faecal transmission is contingent on the amount of viable virus surviving in faeces and urine (Foladori et al., 2020; Guo et al., 2021; Jones D et al., 2020).

Given these findings, it seems timely to examine the risk of SARS-CoV-2 transmission from public toilets in more detail. This article summarises potential risks for acquiring SARS-CoV-2 during a visit to a public toilet and offers some suggestions for mitigating this risk.

2. How could public toilet users acquire SARS-CoV-2?

Acquisition of SARS-CoV-2 occurs following exposure to contaminated air and/or surfaces. There are several possible transmission pathways apparent between an individual and air or surfaces in a public toilet (Figure 1).

2.1. Air

We should first consider the risks from contaminated air. A recent systematic review assessed the degree of air contamination by SARS-CoV-2 in hospitals and found that 24% air samples from toilets were positive, with average viral RNA concentrations per m^3 air higher than for any other area sampled (Birgand et al., 2020). There are additional studies confirming survival and infectivity in air (Lednicky et al., 2020; van Doremalen et al., 2020). Long-range aerosolization due to toilet flushing occurred during an outbreak of SARS-CoV-1 (Amoy Gardens outbreak; Yu et al., 2004) and has been implicated in a SARS-CoV-2 outbreak involving a high-rise building in China, where nine cases lived in three vertically aligned flats connected by drainage pipes between the master bathrooms (Kang et al., 2020).

It is likely that the main risk for airborne transmission comes from inhaling infectious aerosol from a prior user colonised or infected with Covid-19 who is actively shedding virus in expired air (Birgand et al., 2020; Ma et al., 2020). Breathing in aerosolized faecal/urinary material during or after flushing offers an additional risk. This would affect anyone in the bathroom at the time or who enters the cubicle or toilet afterwards within a time interval dependent on particle settling (Birgand et al., 2020; Brönimann et al., 2020; Gerba et al., 1975; Jones D et al., 2020; Knowlton et al., 2018; Lai et al., 2018; Li et al., 2020; Liu et al., 2020; Ma et al., 2020; McDermott et al., 2020; Sassi et al., 2018; Shi et al., 2021; Patel, 2020; Wang J et al., 2020). Bioaerosols may be produced from toilets that are flushed containing no waste, which suggests that the virus could remain in the toilet following prior use (Knowlton et al., 2018; Johnson et al., 2017). The air may also be contaminated by (re)-aerosolized waste water from sewage outlets (Hu et al., 2020), via drains (Shi et al., 2021), spillages, leaks (Yuan et al., 2020; Kang et al., 2020) etc, or incorrectly installed plumbing (Gormley et al., 2021).

2.2. Surfaces: Wash basins

Hand washbasins offer additional sites for release of infectious aerosols in a public toilet (Figure 2). Both surfaces and strainers in washbasins may be contaminated by nasal mucus, saliva and/or sputum due to hand and face washing, and spitting into the sink by users (D'Accolti et al., 2020; Gautret et al., 2020; Wu D et al., 2019). When the next person uses the washbasin, the faucet water jet impinges on the bottom of the basin, which could aerosolise waste secretions. Recent work shows how the faucet aerator design influences the aerosol size distribution from faucet water flows (Benoit et al., 2021). Two ~~elegant~~ experimental studies have revealed how a pathogen is dispersed by handwashing-produced droplets using green fluorescent protein (GFP)-expressing *Escherichia coli* (GFP-*E. coli*), while no dispersal was observed "without or in between faucet events" (Kotay et al., 2017; Kotay et al., 2019). Oral rinsing and spitting means that splashed droplets can re-deposit on surrounding sink surfaces and mirror if present.

2.3. Water sprays and lota

While performing istinja in Islamic community toilets, the use of sprays and lota may also generate droplets (Abdul Rahim, 2005). To date, however, there have been insufficient studies on the potential role of this practice in disease transmission to critically evaluate the risk, particularly when combined with other self-cleansing practices (Mirza, 2009; Nasir and Hamza, 2020).

2.4. Hand hygiene

Poor compliance with hand hygiene facilitates survival and persistence of virus on hands for onward transmission to self or additional surfaces (Cheung M et al., 2020). Even if hands are washed, they may not necessarily be properly dried and wet hands may acquire microbes from the next surface touched (Marcenac et al., 2021). There is also the possibility of (re)-aerosolization of viral particles during or after use of automated hand driers (Huang et al., 2012; Margas et al., 2013). Recent work suggests that hands are more likely to remain contaminated after using a hot air drier rather than paper towels (Moura et al., 2021).

2.5. Bathroom surfaces

SARS-CoV-2 survives on a range of indoor environmental surfaces, such as plastic, stainless steel, glass, ceramics, wood, latex gloves, and surgical masks (van Doremalen et al., 2020; Liu et al., 2021). The virus remains viable for several hours in faeces and 3-4 days in urine (Liu et al., 2021). Such studies uphold sufficient surface longevity of the virus for onward transmission. Risks from bathroom and toilet surfaces would include direct contact with surface splashes of excreta on toilet seats, toilet bowl or other surfaces in near proximity (Figure 2). These present a sequential transmission risk for users if they then touch contaminated skin/surfaces and transfer sufficient viable virus to mucous membranes prior to hand hygiene (Brönimann et al., 2020; Chia et al., 2020; Ding et al., 2020; Döhla et al., 2020; Hu et al., 2020; Ong et al., 2020). Furthermore, fomite contamination offers a host of possible transmission pathways via hand touch surfaces after toilet flushing or direct touch from contaminated hands (e.g. toilet door handles: Cheng et al., 2020; Moore et al., 2020; sink: D'accolti et al., 2020; Döhla et al., 2020; Gautret et al., 2020; Ge et al., 2021; taps, paper towel dispenser, hand dryers, bathroom door handles, etc, Cheung et al., 2020; Verani et al., 2014; Wan et al., 2021; toilet flush: Ge et al., 2021; and toilet paper dispenser: Sassi et al., 2018). These may be contaminated with infective excreta, saliva and/or nasopharyngeal fluids unless sites are cleaned regularly (Chia et al., 2020; Ding et al., 2020; Ong et al., 2020).

3. Can we mitigate the risk of acquiring SARS-CoV-2 in public toilets?

It is not desirable or, indeed, ethically permissible to close toilets in public venues open for business. This means that any toilet facility used outside the home should be subjected to a risk assessment. The literature offers some evidence-based suggestions for safety mitigation in public toilets but others rely on nothing more than common sense. Published recommendations and the authors' own views are categorised for users, managers, bathroom designers and governing bodies. It is hoped that these will stimulate discussion and original research in order to better assess the risk for SARS-Cov-2 acquisition in toilets:

3.1. Advice for users of public toilets (Table)

3.1.1. Support for face coverings (mask) before entering a public toilet: The primary aim is to limit the release of respiratory aerosol and droplets from an infected individual (Chu et al., 2020; Tang et al., 2021).

3.1.2. Closing the toilet lid (if present): It is likely that there is a large upward transport of viral particles after flushing, which could be wholly or partially contained by closing the toilet lid (Gerba et al., 1975; Gormley et al., 2021; Li et al., 2020; McDermott et al., 2020; Patel, 2020; Verani et al., 2014). Modelling suggests 40-60% viral particles generated by flushing will rise above the toilet seat (Li et al., 2020) before settling under the influence of air currents and gravity. Public toilets rarely have lids to contain aerosol and limit pathogen spread.

3.1.3. Hand hygiene: Hands should be washed with running water and soap (if available) and dried well with disposable paper towels (Marcenac et al., 2021). Hand sanitisers may also be used although detergent products are known to inactivate SARS-CoV-2 and do less damage to the environment (Salido et al., 2020; Mahmood et al., 2020). Users should not return to the toilet cubicle for toilet paper to dry hands.

3.1.4. Appropriate use of the washbasin: Masks should also be worn when using a washbasin as well as for toilet use. Discharging nasal or oral secretions directly into the sink is not advised. Paper tissues may be used for expectorating or spitting, followed by safe disposal in a waste bin and followed by handwashing.

3.1.5. Use of mobile devices: There is strong evidence for the role of mobile phones and similar technology as both vectors and reservoirs for infectious agents (Banawas et al., 2018; Bhoonderowa et al., 2014; Sailo et al., 2019; Cheng et al., 2020). Their use in toilet settings should therefore be discouraged.

3.2. Advice for managers of public toilets

3.2.1. Addition of disinfectant into toilet bowl: Deposition of virus-containing droplets on surfaces after flushing infectious waste is significantly reduced if waste is treated with disinfectants (Edmunds et al., 2016; Sassi et al., 2018). This is because organisms can remain in toilets even after several flushes (Johnson et al., 2017). It is appreciated that disinfectants are NOT equal and the choice veers towards products that remain active in the presence of organic waste (Chen C et al., 2006).

3.2.2. Encourage hand-hygiene: Practising good hand-hygiene depends on accessible and functioning sinks; provision of clean water; soap (liquid not bar); clean towels, preferably disposable; or alcohol gel dispenser or comparable hand sanitizer (Amirian, 2020; Cheung M et al., 2020). Waste-bins can be protected by replaceable bags, which should be secured before timely removal. Recent evidence suggests that disposable paper towels are superior to hot air dryers for limiting further spread of pathogens in bathrooms or even outside (Huang et al., 2012; Margas et al., 2013; Moura et al., 2021). Dryers may exacerbate particle settling or perhaps even re-aerosolize deposited respiratory particles on surfaces.

3.2.3. Restricting people-traffic and lengthening the time period between users: Bathroom air is likely to be filled with aerosols generated by multiple toilet flushes within a short time window (Shi et al., 2021). This means that the concentration of airborne virus would be significantly higher if large numbers of carriers converge on the bathroom (Fitzgerald et al., 2021). Limiting people-traffic would help to reduce transmission of larger particles by allowing infectious droplets to settle, though is unlikely to affect risks from smaller particle (aerosol) transmission (Tang et al, 2021). Settling times are dependent upon a number of physicochemical factors such as size, content, temperature, humidity, air turbulence, flush mechanism and pressure, etc. Controlling entrance could be instigated by indicator lights or notices on the outer door. The former is routine in hospital radiology departments and has been adopted by shops to control occupancy during the pandemic.

3.2.4. Restrict urinal choice in gents' toilets: With little or no supporting evidence, this suggestion aims to increase physical distance between men while urinating in order to limit exposure to urinary aerosol.

3.2.5 Increase ventilation: The ability to implement this varies between toilet facilities. Some will be mechanically ventilated and others rely on natural sources (open windows) (Meng et al., 2020; Liu et al., 2020). If windows can be opened, subject to thermal comfort and security, then risks from aerosol transmission are reduced, particularly if prevailing air flow moves directly from inlet to outlet without circulation (Morawska et al., 2020). Toilets for daily use could leave windows open overnight or at weekends, although this depends upon security and factors such as temperature, weather, people-traffic and pollution. Open windows would not necessarily alleviate risk during periods of heavy usage. Facilities which employ mechanical ventilation should review the system *in situ* and consider increasing air changes per hour or replacing a mixed or recirculating air system with one that uses only fresh air (Morawska et al., 2020). There are air filtration units and high level air disinfection strategies available for facilities at specific risk although these may entail major refurbishment and extra cost.

3.2.6 Increase cleaning frequency: Cleaning and decontamination are critical but while the methods remain fairly standard, the frequency depends upon people-traffic and this is unlikely to be monitored (Amirian, 2020; Shimabukuro et al., 2020; Fitzgerald et al., 2021). Most public toilets are cleaned just once per day; this is not sufficient to protect users in areas reporting rising transmission rates (Carling et al., 2009). There is little evidence to support cleaning frequencies for any indoor surfaces, including hospitals. Cleaning has only recently been accepted as an evidence-based science (Dancer, 1999). The World Health Organisation (WHO, 2020) specifies workplaces for 'jobs at medium risk' should receive twice daily cleaning and disinfection of objects and surfaces that are frequently touched, in shared rooms, bathrooms, and changing rooms. The products used should be effective against enveloped viruses along with other common surface pathogens. Most guidance supports detergent for preliminary removal of surface soil followed by disinfectant at a dilution of 1,000 parts per million available chlorine (ppm av. cl.). Cleaning guidance is available for trained cleaning staff, with check lists and time sheets for all facilities (Scottish Government, 2020).

3.2.7. Maintenance and functional monitoring: The maintenance and monitoring of toilet function and sinks are also of critical importance, given the implications from a blocked or leaking toilet, defective plumbing or malfunctioning sink (Gormley et al., 2017; Gormley et al., 2021; Kang et al., 2020; Kotay et al., 2017; Meng et al., 2020; Del Bruto et al., 2020a).

3.3. Advice for bathroom designers

3.3.1. Use all available space: Toilets should be designed to maximise space as far as possible. This suggestion aims to encourage dilution of airborne microorganisms and reduce transmission risk.

3.3.2. Bathroom location: Consideration should be given to bathroom location in a public facility; this would include ease of access (including disabled access) and presence of windows and doors to permit ingress of fresh air and sunlight if possible (Panek et al., 2005).

3.3.3. Choice of surface materials: Given the risk from surface survival of pathogens including SARS-CoV-2, it is best to use durable materials that can withstand disinfectants, demonstrate longevity and are easy to clean (Dancer, 2014). Some materials repel pathogen adhesion whereas others may attract organic soil including microbes (Inkinen et al., 2017). This includes fixtures and fittings, such as toilet flush, toilet paper holder, sink surround and automated dryers if present.

3.3.4. Choice of flush mechanism: Flushing systems that minimise production of aerosol are advocated (Johnson et al., 2013) The cistern tank design has been reported to be the preferred toilet flushing option due to minimal generation of potentially infectious small aerosols (Lai et al., 2018).

3.3.5. High throughput ventilation: Achieving this depends upon the choice between mechanical ventilation systems and natural ventilation (open windows) (Liu et al., 2020; Meng et al., 2020; Morawska et al., 2020;). In mechanically ventilated public toilets, the required minimum ventilation rates are 35 L/s per water closet and/or urinal for theatres, schools, and sports facilities where heavy use may occur; and 25 L/s in other toilets (ASHRAE, 2019). Hence if ventilation in public toilets is properly designed and operated, the ventilation conditions should be entirely adequate. Risk of airborne infection is more likely in toilets with poor ventilation or for short-range transmission when using washbasins since people tend to lean towards the sink when using it.

3.3.6. Hand drying resources: As already mentioned, disposable paper towels are superior to hot air dryers for limiting further spread of pathogens in bathrooms or even outside (Huang et al., 2012; Margas et al., 2013; Moura et al., 2021). Dryers may exacerbate particle settling or perhaps even re-aerosolize deposited respiratory particles on surfaces. Automatic paper feed dispensers are an alternative choice.

3.3.7. Access for all: Bathroom design needs to ensure that all segments of the population (including physically and mentally disabled individuals, elderly, blind and children) are able to follow good hygiene practices (Panek et al., 2005). This dictates signage, door, tap and handle placement, space for wheelchairs, accessible towel dispensers, contactless (sensor) flush and taps, revolving or automatic access doors and electronic hand hygiene reminders if possible. Toilets frequented by children and/or the elderly should be subject to additional design strategies, given that these persons are either going to be more vulnerable to Covid-19, or more likely to be shedding the virus.

3.3.8. Increase natural daylight: Given the virucidal effect of UV light, it would be helpful to encourage ingress of sunlight into toilet facilities (Ratnesar-Shumate et al., 2020; Ren et al., 2020). While this is clearly dependant on window opening and position, climate and season, there are options for introducing artificial ultraviolet light into contained indoor environments (Morawska et al., 2020; Rodríguez et al., 2021).

3.3.8. Next-generation toilets: There are many design modifications to toilets and cubicles that could be made to reduce the number of contact surfaces and reduce aerosolization. Examples of this include the use of vacuum toilets with non-stick bowls commonly used on aircraft, lid activated UV-light for disinfection, no toilet-paper-cleansing (*in situ* bidet function), hands-free taps, and automatic soap dispensers and door latches. There may be a role for futuristic antimicrobial surfaces such as copper or silver for common touch-points (Dancer, 2014; Inkinen et al., 2017). Further work is required to quantify the importance of these features in reducing transmission risk.

3.4. Advice for governing bodies

3.4.1. Public education campaigns: The potential risk associated with toilet use should be promoted using social media, newspapers, television and radio; this would help to highlight potential risks from public toilet use and the need to maintain good personal hygiene (Okello et al., 2019; Wu et al., 2019). Many countries would benefit from educational campaigns given the studies showing poor compliance with hand hygiene and other practices in public toilets (Hateley and Jumaa, 1999; Wu et al., 2019).

3.4.2. Public opinion: Improving public opinion would help to focus local and national government on safe management of public toilets, for those that use them and those that design, engineer, clean or maintain them. Hospital patients frequently speak out about facilities that they consider to be dirty Edgcumbe, 2009).

It should be noted that many of the interventions highlighted above are likely to reduce the spread and subsequent infections from other enteric and respiratory viruses.

4. Discussion

Current evidence suggest that public toilets constitute a risk for transmission of SARS-CoV-2 (Wong et al., 2020). This is because all the key transmission pathways involving surfaces and air converge in an area likely to be heavily contaminated and frequently used (Meyerowitz et al., 2020). Poorly ventilated indoor toilets encourage inhalation of airborne particles containing SARS-CoV-2 shed from prior users. Toilet access, use, and hand hygiene require direct and indirect handling of common hand-touch sites in bathrooms, which are likely to be contaminated by users. These sites include door handles/lock, taps, toilet flush, grab handles, switches, paper towel dispenser, toilet roll holder and toilet seat. It is difficult to use a toilet without touching any or several of these surfaces. The propensity for contamination is directly proportional to the frequency of touch (Adams et al., 2017). Viral transmission in bathrooms becomes even more pertinent when it is apparent that viral shedding from faeces continues even after respiratory samples become negative (Yifei Chen et al., 2020).

Public toilets also pose a risk to people who are employed to clean, maintain, inspect, service or repair them. Plumbers, cleaners, bathroom managers and sanitation inspectors are at risk of acquiring the virus through direct or indirect contact or inhalation of aerosols in toilet areas. While sewage workers are provided with respirators and other personal protective equipment, the same is not usually true for sanitary plumbers or cleaners (Amirian, 2020). As yet, there is no evidence for occupational acquisition of SARS-CoV-2 among sewage workers.

Studies of SARS-CoV-2 in toilets have so far been conducted in healthcare environments, which have higher frequency of, and more thorough, cleaning regimens than public toilets (Birgand et al., 2020; Cheng et al., 2020; Chia et al., 2020; D'Accolti et al., 2020; Jiang et al., 2020; Razzini et al., 2020; Santarpia et al., 2020; Shimabukuro et al., 2020; Wan et al., 2021; Ye et al., 2020). Despite this, faecal-derived aerosols in patients' toilets contained most of the detected SARS-CoV-2 in one hospital (Ding et al., 2020). Outside hospitals, two linked studies investigated use of open latrines (no flushing system) and identified a cluster of seropositive Covid-19 patients associated with use of shared latrines (Del Bruto et al., 2020a; Del Bruto et al., 2020b). A widely neglected aspect of virus containment is that a major part of the population in developing regions do not have access to private, clean sanitary facilities (Mallory et al., 2020; Sun S et al., 2020). It is possible that open defaecation and use of squat toilets are additional risk factors in these communities. At least 20 countries reporting more than 10,000 confirmed infections have 5-26% of their population practicing open defaecation. This is particularly notable in rural India, where over half of the population do not use Western-type lavatories (Novotný et al, 2018). This country has been severely affected by Covid-19. Poor hand hygiene, contaminated shoes and objects, mechanical vectors, and outdoor human activities could all contribute to faecal transmission. Other risk factors include squat pans with lidless designs and open flushing mechanisms, open waste bins in the cubicle and lack of water-sealing U-traps in squat toilets (Sun S et al., 2020).

There has been little sampling or epidemiological data on viral prevalence or transmission from public toilets as they have generally been closed during the lock-down (Global Times, 2020). However, there is evidence for the potential role of domestic toilets as a significant risk for viral acquisition. In 2003, there was a large community outbreak of SARS in Hong Kong, affecting more than 300 residents in Amoy Gardens. This was presumed to be related to faecal–oral transmission (Hong Kong Government, 2003) and most likely faecal-aerosol transmission (Yu et al., 2004). A SARS patient with diarrhoea visited the Amoy Gardens building and used the toilet; subsequently, 321 cases of SARS were located in clusters within this building. More recently, faecal–aerosol transmission might have caused the community outbreak of COVID-19 in a high-rise building in Guangzhou, China (Kang et al., 2020). Nine patients from three families lived in vertically aligned flats connected by drainage pipes in the master bathrooms. The first family to become symptomatic had visited Wuhan in January 2020, whilst the other two families lacked any travel history and became ill in February 2020. There was no evidence that transmission had occurred through communal access points, including the elevator. Both the timing of infections and the location of positive environmental samples supported vertical spread of virus-laden aerosols via stacks and vents (Kang et al., 2020).

One of the major concerns with Ebola virus infectious waste was the high concentration of viral particles shed in stool (10^7/mL) (Bibby et al., 2015). This can be compared against the median faecal viral load of 10^5/mL for SARS-CoV-2 in patients with diarrhoea (Cheung K et al., 2020). In some cases, the viral load of SARS-CoV-2 in faeces reaches 10^7 copies/g, which is higher than that in pharyngeal swabs (Wolfel et al., 2020). Recommendations on critical control points, including toilets, and containment for Ebola virus waste have been outlined by WHO (Edmunds et al., 2016).

If toilets are a hub for infection transmission, then it is reasonable to consider COVID-19 infection rates among workers in relevant occupations. People who clean or maintain toilets or supervise others using them might demonstrate higher rates of infection. A study of work-related COVID-19 infection patterns in Asia rated the top five jobs for infection risk as healthcare workers (HCWs), drivers and transport workers, sales workers, cleaning and domestic workers, and public safety workers (Lan et al., 2020). According to the UK's Office for National Statistics (ONS, 2020), there were two major groups of occupations found to have high rates of death involving COVID-19. The first was construction workers and cleaners, and the second included occupations such as nursing assistants and care workers. WHO themselves define occupations with high exposure risk as domestic workers, social care workers and home repair technicians (plumbers, electricians) who provide services in the homes of people with COVID-19 (WHO, 2020). Given the proclivity of occupations with toilet-related jobs, domestic and maintenance staff should be offered training and personal protective equipment as a safety measure subject to further evidence.

Almost everyone requires regular access to a toilet (Stanwell-Smith, 2010). Relaxation of lock down in the UK during summer 2020 allowed people to explore the seaside, countryside and towns and cities. Whether a beach or a bar, adjoining toilets are always needed and will be heavily used (Fitzgerald et al., 2021). Careful and detailed epidemiological studies are required to link toilet use with infection incidence. This has been done for norovirus, during air and boat travel, and restaurant visits, where confirmed cases using the bathroom/toilet were linked with norovirus acquisition (Boxman et al., 2009; Carling et al., 2009; Chimonas et al., 2008; Ho et al., 1989; Jones E et al., 2007; Leone et al., 2016; Widdowson et al., 2005). Other pathogenic viruses have been associated with toilets in offices and hospital, with the most contaminated surfaces reported as bathroom door handles (66%), flushing buttons (62%), toilet seats (59%), and toilet covers (52%) (Verani et al., 2014). One recent study examined transmission risk from different venues in China without specifying toilet use (Zhao et al., 2020). The study found that while most clusters occurred in the home, there was strong evidence for case clustering in public buildings. The question should be asked as to whether public building access also included use of toilets (Cai et al., 2020).

5. Conclusion

The evidence presented here indicates that transmission of SARS-CoV-2 within public toilets is a potential risk, requiring further research, particularly around airborne or contact-transmitted minimum infectious doses generated from excreta. Without such evidence, toilet-related SARS-CoV-2 transmission risk will not receive the attention it deserves from toilet user, cleaner, manager or designer viewpoints. In particular, cleaners who are regularly exposed to such contaminated environments, and who are low paid with low status, yet are crucial for reducing infection in hospitals and communities, have only relatively recently come to the attention of facilities managers. The next step, in the context of COVID-19, is to ensure adequate ventilation for toilets, and indeed, all indoor venues.

Acknowledgements

This review was compiled by the authors following helpful discussion with the Transmission of SARS-CoV-2 in the Wider Environment Group (TWEG), DEFRA, London, UK. Special thanks go to David Graham for support and references. DLJ was supported by the UK Natural Environment Research Council COVID-19 response grant NE/V004883/1.

CRediT authorship contribution statement

Conceptualization: SJD; Data curation: SJD, AH, YL, JWT, DLJ; Formal analysis: SJD, YL; Literature search: SJD, YL, AH, JWT, DLJ; Additional material: AH; Figures: YL, SJD; Original draft: SJD; Review & editing: SJD, YL, AH, JWT, DLJ.

Declarations of Interest

No relevant declarations of interest for any author

References

Abdul Rahim, A., 2005. A concept of clean toilet from the Islamic perspective. Journal of Islamic Built Environment 1, 71-84.

Adams, C.E., Smith, J., Watson, V., Robertson, C., Dancer, S.J., 2017. Examining the association between surface bioburden and frequently touched sites in intensive care. Journal of Hospital Infection 95, 76-80.

Ahmed, W., Angel, N., Edson, J., et al. 2020. First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. Science of the Total Environment 728, 138764.

Amirian, E.S., 2020. Potential fecal transmission of SARS-CoV-2: Current evidence and implications for public health. International Journal of Infectious Diseases 95, 363–370.

ASHRAE, 2019. Standard 62.1.2019. Ventilation for acceptable indoor air quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

Banawas, S., Abdel-Hadi, A., Alaidarous, M., Alshehri, B., Bin Dukhyil, A.A., Alsaweed, M., Aboamer, M., 2018. Multidrug-resistant bacteria associated with cell phones of healthcare professionals in selected hospitals in Saudi Arabia. The Canadian journal of Infectious Diseases & Medical Microbiology 2018, 6598918.

Benoit, M.È., Prévost, M., Succar, A., Charron, D., Déziel, E., Robert, E., Bédard, E., 2021. Faucet aerator design influences aerosol size distribution and microbial contamination level. Science of the Total Environment 775, 145690.

Bhoonderowa, A., Gookool, S., Biranjia-Hurdoyal, S.D., 2014. The importance of mobile phones in the possible transmission of bacterial infections in the community. Journal of Community Health 39, 965–967.

Bibby, K., Fischer, R.J., Casson, L.W., Stachler, E, Haas, C.N., Munster, V.J., 2015. Persistence of Ebola virus in sterilized wastewater. Environmental Science and Technology Letters 8, 245-249.

Birgand, G., Peiffer-Smadja, N., Fournier, S., Kerneis, S., Lescure, F.X., Lucet, J.C., 2020. Assessment of air contamination by SARS-CoV-2 in hospital settings. JAMA Network Open. 1, e2033232.

Boxman, I., Dijkman, R., Verhoef, L., Maat, A., van Dijk, G., Vennema, H., Koopmans, M., 2009. Norovirus on swabs taken from hands illustrate route of transmission: a case study. Journal of Food Protection 72, 1753-1755.

Brönimann, S., Rebhan, K., Lemberger, U., Misrai, V., Shariat, S.F., Pradere, B., 2020. Secretion of severe acute respiratory syndrome coronavirus 2 in urine. Current Opinion in Urology 30, 735-739.

Bwire, G.M., Majigo, M.V., Njiro, B.J., Mawazo, A., 2020. Detection profile of SARS-CoV-2 using RT-PCR in different types of clinical specimens: A systematic review and meta-analysis. Journal of Medical Virology 93, 719-725.

Cai, J., Sun, W., Huang, J., Gamber, M., Wu, J., He, G., 2020. Indirect virus transmission in cluster of COVID-19 cases, Wenzhou, China, 2020. Emerging and Infectious Diseases 26, 1343-1345.

Cao, Y., & Francis, R., 2021. On forecasting the community-level COVID-19 cases from the concentration of SARS-CoV-2 in wastewater. The Science of the Total Environment 786, 147451.

Carling, P.C., Bruno-Murtha, L.A., Griffiths, J.K., 2009. Cruise ship environmental hygiene and the risk of norovirus infection outbreaks: an objective assessment of 56 vessels over 3 years. Clinical Infectious Diseases 49, 1312-1317.

Casanova, L., Rutala, W.A., Weber, D.J., Sobsey, M.D., 2009. Survival of surrogate coronaviruses in water. Water Research 43, 1893-1898.

Chen, C., Zhang, X. J., Wang, Y., Zhu, L. X., & Liu, J., 2006. Waste water disinfection during SARS epidemic for microbiological and toxicological control. Biomedical and environmental sciences: BES, 19(3), 173–178.

Chan, M. C., Sung, J. J., Lam, R. K., Chan, P. K., Lee, N. L., Lai, R. W., Leung, W.K., 2006. Fecal viral load and norovirus-associated gastroenteritis. Emerging Infectious Diseases 12, 1278–1280.

Chen, Y., Guo, Y., Pan, Y., Zhao, Z.J., 2020. Structure analysis of the receptor binding of 2019-nCoV. Biochemical and Biophysical Research Communications 17, 135–140.

Chen, Y., Chen, L., Deng, Q., Zhang, G., Wu, K., Ni, L., Yang, Y., Liu, B., Wang, W., Wei, C., Yang, J., Ye, G., Cheng, Z., 2020. The presence of SARS-CoV-2 RNA in the feces of COVID-19 patients. Journal of Medical Virology 92, 833-840.

Cheng, V.C., Wong, S.C., Chan, V.W., So, S.Y., Chen, J.H., Yip, C.C., Chan, K.H., Chu, H., Chung, T.W., Sridhar, S., To, K.K., Chan, J.F., Hung, I.F., Ho, P.L., Yuen, K.Y., 2020. Air and environmental sampling for SARS-CoV-2 around hospitalized patients with coronavirus disease 2019 (COVID-19). Infection Control & Hospital Epidemiology 41, 1258-1265.

Cheung, K. S, Hung, I.F.N., Chan, P.P.Y., Lung, K.C., Tso, E., Liu, R., Ng, Y.Y., Chu, M.Y., Chung, T.W.H., Tam, A.R., Yip, C.C.Y., Leung, K.H., Fung, A.Y., Zhang, R.R., Lin, Y., Cheng, H.M., Zhang, A.J.X., To, K.K.W., Chan, K.H., Yuen, K.Y., Leung, W.K., 2020. Gastrointestinal

Manifestations of SARS-CoV-2 Infection and Virus Load in Fecal Samples from a Hong Kong Cohort: Systematic Review and Meta-analysis. Gastroenterology 159(1), 81-95.

Cheung, M.M.F., Suen, L.K.P., Au, J.K.L., Lam, S.C., 2020. Bioluminescence-based hygiene evaluation of public washroom environment: Repeated measurement of post-handwashing facilities on baseline and before and after cleaning schedule. American Journal of Infection Control, S0196-6553(20)30960-3.

Chia, P. Y., Coleman, K. K., Tan, Y. K., Ong, S., Gum, M., Lau, S. K., Lim, X. F., Lim, A. S., Sutjipto, S., Lee, P. H., Son, T. T., Young, B. E., Milton, D. K., Gray, G. C., Schuster, S., Barkham, T., De, P. P., Vasoo, S., Chan, M., Ang, B., Singapore 2019 Novel Coronavirus Outbreak Research Team (2020). 2020. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. Nature Communications 11, 2800

Chimonas, M.A., Vaughan, G.H., Andre, Z., Ames, J.T., Tarling, G.A., Beard, S., Widdowson, M.A., Cramer, E., 2008. Passenger behaviors associated with norovirus infection on board a cruise ship, Alaska, May to June 2004. Journal of Travel Medicine 15, 177-183.

Chu, D.K., Akl, E.A., Duda, S., Solo, K., Yaacoub, S., Schünemann, H.J., COVID-19 Systematic Urgent Review Group Effort (SURGE) study authors, 2020. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. Lancet 395, 1973-1987.

D'Accolti, M., Soffritti, I., Passaro, A., Zuliani, G., Antonioli, P., Mazzacane, S., Manfredini, R., Caselli, E., 2020. SARS-CoV-2 RNA contamination on surfaces of a COVID-19 ward in a hospital of Northern Italy: what risk of transmission? European Review for Medical and Pharmacological Sciences 24, 9202-9207.

Dancer, S.J., 2014. Controlling hospital-acquired infection: focus on the role of the environment and new technologies for decontamination. Clinical Microbiology Review 27, 665-690.

Dancer, S.J., 1999. Mopping up hospital infection. Journal of Hospital Infection 43, 85-100.

Del Brutto, O.H., Costa, A.F., García, H.H., 2020a. Incident SARS-CoV-2 infection and a shared latrine. The American Journal of Tropical Medicine and Hygiene 103, 941-942.

Del Brutto, O.H., Costa, A.F., Mera, R.M., Recalde, B.Y., Bustos, J.A., García, H.H., 2020b. Late incidence of SARS-CoV-2 infection in a highly-endemic remote rural village. A prospective population-based cohort study. Pathogens and Global Health. 114, 457-462.

Ding, Z., Qian, H., Xu, B., et al. 2020. Toilets dominate environmental detection of SARS-CoV-2 virus in a hospital. Science of the Total Environment 753, 141710.

Döhla, M., Wilbring, G., Schulte, B., Kümmerer, B.M., Diegmann, C., Sib, E., 2020. SARS-CoV-2 in environmental samples of quarantined households. MedRxiv preprint, posted June 2, 2020. doi: 10.1101/2020.05.28.20114041

Edgcumbe, D.P., 2009. Patients' perceptions of hospital cleanliness are correlated with rates of meticillin-resistant *Staphylococcus aureus* bacteraemia. Journal of Hospital Infection 71, 99-101.

Edmunds, K.L., Elrahman, S.A., Bell, D. J., Brainard, J., Dervisevic, S., Fedha, T.P., Few, R., Howard, G., Lake, I., Maes, P., Matofari, J., Minnigh, H., Mohamedani, A.A., Montgomery, M., Morter, S., Muchiri, E., Mudau, L.S., Mutua, B.M., Ndambuki, J.M., Pond, K., Hunter, P.R., 2016. Recommendations for dealing with waste contaminated with Ebola virus: a Hazard Analysis of Critical Control Points approach. Bulletin of the World Health Organization, 94(6), 424–432.

Fitzgerald, N., Uny, I., Brown, A., Eadie, D., Ford, A., Lewsey, J., Stead, M., 2021. Managing COVID-19 transmission risks in bars: An interview and observation study. Journal of Studies on Alcohol and Drugs 82, 42-54.

Foladori, P., Cutrupi, F., Segata, N., Manara, S., Pinto, F., Malpei, F., Bruni, L., La Rosa, G., 2020. SARS-CoV-2 from faeces to wastewater treatment: what do we know? A review. Science of the Total Environment 743, 140444.

Gautret, P., Colson, P., Lagier, J. C., Parola, P., & Raoult, D, 2020. Does spitting in public play a role in transmitting SARS-CoV-2? Travel Medicine and Infectious Disease, 36, 101759.

Ge, T., Lu, Y., Zheng, S., Zhuo, L., Yu, L., Ni, Z., Zhou, Y., Ni, L., Qu, T., Zhong, Z., 2021. Evaluation of disinfection procedures in a designated hospital for COVID-19. American Journal of Infection Control 49, 447-451.

Gerba, C.P., Wallis, C., Melnick, J.L., 1975. Microbiological hazards of household toilets: droplet production and the fate of residual organisms. Applied Microbiology 30, 229-237.

Global Times, 2020. Two of Beijing's COVID-19 cases infected from a public toilet. https://www.globaltimes.cn/content/1192683.shtml accessed on 26 June 2020.

Gormley, M., Aspray, T.J., Kelly, D.A., Rodriguez-Gil, C., 2017. Pathogen cross-transmission via building sanitary plumbing systems in a full scale pilot test-rig. PLoS One 10, e0171556.

Gormley, M., Aspray, T.J., Kelly, D.A., 2021. Aerosol and bioaerosol particle size and dynamics from defective sanitary plumbing systems. Indoor Air Feb 10, in press.

Greed, C., 2004. Public toilets: the need for compulsory provision. Proceedings of the Institution of Civil Engineers - Municipal Engineer 157, 77-85.

Gu, J., Han, B., Wang, J., 2020. COVID-19: gastrointestinal manifestations and potential fecal-oral transmission. Gastroenterology 158, 1518–1519.

Guo, M., Tao, W., Flavell, R.A., Zhu, S., 2021. Potential intestinal infection and faecal-oral transmission of SARS-CoV-2. Nature Reviews. Gastroenterology & Hepatology 18, 269–2835.

Gupta, S., Parker, J., Smits, S., Underwood, J., Dolwani, S., 2020. Persistent viral shedding of SARS-CoV-2 in faeces - a rapid review. Colorectal Disease 22, 611-20.

Hateley, P. M., & Jurnaa, P. A., 1999. Hand washing is more common among healthcare workers than the public. BMJ (Clinical research ed.), 319(7208), 519.

He, Y., Wang, Z., Li, F., Shi, Y., 2020. Public health might be endangered by possible prolonged discharge of SARS-CoV-2 in stool. Journal of Infection 80, e18-e19.

Ho, M.S., Glass, R.I., Monroe, S.S., Madore, H.P., Stine, S., Pinsky, P.F., Cubitt, D., Ashley, C., Caul, E.O., 1989. Viral gastroenteritis aboard a cruise ship. Lancet 2, 961-5.

Hong Kong Government, 2003. WHO Environmental Health Team reports on Amoy Gardens. Hong Kong Government https://www.info.gov.hk/gia/general/200305/16/0516114.htm (2003).

Hu, X., Xing, Y., Ni, W., Zhang, F., Lu, S., Wang, Z., Gao, R., Jiang, F., 2020. Environmental contamination by SARS-CoV-2 of an imported case during incubation period. Science of the Total Environment 742, 140620.

Huang, C., Ma, W., Stack, S., 2012. The hygienic efficacy of different hand-drying methods: a review of the evidence. Mayo Clinic Proceedings 87, 791-8.

Inkinen, J., Mäkinen, R., Keinänen-Toivola, M.M., Nordström, K., Ahonen, M., 2017. Letters in Applied Microbiology 64(1):19-26.

Jeong, H.W., Kim, S.M., Kim, H.S., Kim, Y.I., Kim, J.H., Cho, J.Y., Kim, S.H., Kang, H., Kim, S.G., Park, S.J., Kim, E.H., Choi, Y.K., 2020. Viable SARS-CoV-2 in various specimens from COVID-19 patients. Clinical Microbiology and Infection 26, 1520-1524.

Jiang, F.C., Jiang, X.L., Wang, Z.G., Meng, Z.H., Shao, S.F., Anderson, B.D., Ma, M.J., 2020. Detection of Severe Acute Respiratory Syndrome Coronavirus 2 RNA on surfaces in quarantine rooms. Emerging and Infectious Diseases 26, 2162–2164.

Johnson, D., Lynch, R., Marshall, C., Mead, K., Hirst D., 2013. Aerosol Generation by Modern Flush Toilets. Aerosol Science and Technology 47(9), 1047-1057.

Johnson, D.L., Lynch, R.A., Villanella, S.M., Jones, J.F., Fang, H., Mead, K.R., Hirst, D.V.L., 2017. Persistence of Bowl Water Contamination during Sequential Flushes of Contaminated Toilets. Journal of Environmental Health 80(3), 34-49.

Jones, D.L., Baluja, M.Q., Graham, D.W., Corbishley, A., McDonald, J.E., Malham, S.K., Hillary, L.S., Connor, T.R., Gaze, W.H., Moura, I.B., Wilcox, M.H., Farkas, K., 2020 Shedding of SARS-CoV-2 in feces and urine and its potential role in person-to-person transmission and the environment-based spread of COVID-19. Science of the Total Environment 749, 141364.

Jones, E.L., Kramer, A., Gaither, M., Gerba, C.P., 2007. Role of fomite contamination during an outbreak of norovirus on houseboats. International Journal of Environmental Health Research 17, 123-131.

Kang, M., Wei, J., Yuan, J., Guo, J., Zhang, Y., Hang, J., Qu, Y., Qian, H., Zhuang, Y., Chen, X., Peng, X., Shi, T., Wang, J., Wu, J., Song, T., He, J., Li, Y., Zhong, N., 2020. Probable evidence of fecal aerosol transmission of SARS-CoV-2 in a high-rise building. Annals of Internal Medicine 173, 974–980.

Kotay, S., Chai, W., Guilford, W., Barry, K., Mathers, A.J., 2017. Spread from the sink to the patient: In situ study using green fluorescent protein (GFP)-expressing *Escherichia coli* to model bacterial dispersion from hand-washing sink-trap reservoirs. Applied and Environmental Microbiology 83, e03327-16.

Kotay, S.M., Donlan, R.M., Ganim, C., Barry, K., Christensen, B.E., Mathers, A.J., 2019. Droplet- rather than aerosol-mediated dispersion is the primary mechanism of bacterial transmission from contaminated hand-washing sink traps. Applied and Environmental Microbiology 85, e01997-18.

Knowlton, S. D., Boles, C. L., Perencevich, E. N., Diekema, D. J., Nonnenmann, M. W., & CDC Epicenters Program, 2018. Bioaerosol concentrations generated from toilet flushing in a hospital-based patient care setting. Antimicrobial Resistance and Infection Control 7, 16.

Lai, A.C.K., Tan, T.F., Li, W.S., Ip, D.K.M., 2018. Emission strength of airborne pathogens during toilet flushing. Indoor Air 28, 73–79.

Lan, F.Y., Wei, C.F., Hsu, Y.T., Christiani, D.C., Kales, S.N., Work-related COVID-19 transmission in six Asian countries/areas: A follow-up study. PLoS One 15, e0233588.

Lednicky, J.A., Lauzardo, M., Fan, Z.H., Jutla, A., Tilly, T.B., Gangwar, M, et al. 2020. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. International Journal of Infectious Disease 100, 476-482.

Leone, C.M., Tang, C., Sharp, J., Jiang, X., Fraser, A., 2016. Presence of human noroviruses on bathroom surfaces: a review of the literature. International Journal of Environmental Health Research 26, 420-432.

Liu, Y., Li, T., Deng, Y., Liu, S., Zhang, D., Li, H., Wang, X., Jia, L., Han, J., Bei, Z., Li, L., Li, J., 2021. Stability of SARS-CoV-2 on environmental surfaces and in human excreta. Journal of Hospital Infection 107:105-107.

Liu, Y., Ning, Z., Chen, Y., et al. 2020. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. Nature 582, 557-560.

Li, Y.Y., Wang, J.X., Chen, X., 2020. Can a toilet promote virus transmission? From a fluid dynamics perspective. Physics of Fluids 32, 065107.

Lodder, W., de Roda Husman, A.M., 2020. SARS-CoV-2 in wastewater: potential health risk, but also data source. Lancet Gastroenterology and Hepatology 5, 533-534.

Ma, J., Qi, X., Chen, H., Li, X., Zhang, Z., Wang, H., Sun, L., Zhang, L., Guo, J., Morawska, L., Grinshpun, S.A., Biswas, P., Flagan, R.C., Yao, M., 2020. COVID-19 patients in earlier stages exhaled millions of SARS-CoV-2 per hour. Clinical Infectious Diseases 28, ciaa1283.

Mahmood, A., Eqan, M., Pervez, S., Alghamdi, H. A., Tabinda, A. B., Yasar, A., Brindhadevi, K., & Pugazhendhi, A, 2020. COVID-19 and frequent use of hand sanitizers; human health and environmental hazards by exposure pathways. The Science of the Total Environment 742, 140561.

Mallory, A., Akrofi, D., Dizon, J., Mohanty, S., Parker, A., Rey Vicario, D., Prasad, S., Welivita, I., Brewer, T., Mekala, S., Bundhoo, D., Lynch, K., Mishra, P., Willcock, S., & Hutchings, P., 2020. Evaluating the circular economy for sanitation: Findings from a multi-case approach. The Science of the Total Environment 744, 140871.

Marcenac, P., Kim, S., Molinari, N., Person, M., Frankson, R., Berendes, D., McDonald, C., Yoder, J., Hil,l V., Garcia-Williams, A., 2021. Knowledge, attitudes, and practices around hand drying in public bathrooms during the COVID-19 pandemic in the United States. American Journal of Infection Control S0196-6553(21), 00169-3.

Margas, E., Maguire, E., Berland, C.R., Welander, F., Holah, J.T., 2013. Assessment of the environmental microbiological cross contamination following hand drying with paper hand towels or an air blade dryer. Journal of Applied Microbiology 115, 572-582.

McDermott, C.V., Alicic, R.Z., Harden, N., Cox, E.J., Scanlan, J.M., 2020. Put a lid on it: are faecal bio-aerosols a route of transmission for SARS-CoV-2? Journal of Hospital Infection 105, 397-398.

Medema, G., Heijnen, L., Elsinga, G., Italiaander, R., Brouwer, A., 2020. Presence of SARS-Coronavirus-2 in sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in The Netherlands. Environmental Science & Technology Letters 7(7), 511-516.

Meng, X., Huang, X., Zhou, P., et al. 2020. Alert for SARS-CoV-2 infection caused by fecal aerosols in rural areas in China. Infection Control & Hospital Epidemiology 41, 987.

Meyerowitz, E.A., Richterman, A., Gandhi, R.T., Sax, P.E., 2020. Transmission of SARS-CoV-2: A review of viral, host, and environmental factors. Annals of Internal Medicine 174, 69-79.

Mirza, B.F., 2009. Hygiene i islam og dagens medisin. Masters thesis, University of Oslo, Oslo, Norway.

Moore, G., Rickard, H., Stevenson, D., Aranega-Bou, P., Pitman, J., Crook, A., Davies, K., Spencer, A., Burton, C., Easterbrook, L., Love, H. E., Summers, S., Welch, S. R., Wand, N., Thompson, K. A., Pottage, T., Richards, K. S., Dunning, J., Bennett, A., 2021. Detection of SARS-CoV-2 within the healthcare environment: a multicentre study conducted during the first wave of the COVID-19 outbreak in England. Journal of Hospital Infection 108, 189-196.

Morawska, L., Tang, J. W., Bahnfleth, W., Bluyssen, P. M., Boerstra, A., Buonanno, G., Cao, J., Dancer, S.J., Floto, A., Franchimon, F., Haworth, C., Hogeling, J., Isaxon, C., Jimenez, J. L., Kurnitski, J., Li, Y., Loomans, M., Marks, G., Marr, L. C., Mazzarella, L., Yao, M., 2020. How can airborne transmission of COVID-19 indoors be minimised? Environment International 142, 105832.

Moura, I.B., Ewin, D., Wilcox, M.H., 2021. From the hospital toilet to the ward: A pilot study on microbe dispersal to multiple hospital surfaces following hand drying using a jet air dryer versus paper towels. Infection Control & Hospital Epidemiology Mar 17, 1-4.

Nasir, M.S., Hazma, S., 2020. How to combat the coronavirus from Islamic perspective. Pearson Journal of Social Sciences & Humanities 6, 136-147.

Novotný, J., Ficek, F., Hill, J., & Kumar, A., 2018. Social determinants of environmental health: A case of sanitation in rural Jharkhand. The Science of the Total Environment 643, 762–774.

Okello, E., Kapiga, S., Grosskurth, H., Makata, K., Mcharo, O., Kinungh'i, S., Dreibelbis, R., 2019. Factors perceived to facilitate or hinder handwashing among primary students: a qualitative assessment of the Mikono Safi intervention schools in NW Tanzania. BMJ Open 9, e030947.

Ong, S., Tan, Y. K., Chia, P. Y., Lee, T. H., Ng, O. T., Wong, M., Marimuthu, K., 2020. Air, surface environmental, and personal protective equipment contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from a symptomatic patient. JAMA 323, 1610-1612.

ONS (Office for National Statistics). Coronavirus (COVID-19) related deaths by occupation, England and Wales: deaths registered between 9 March and 25 May 2020, ONS, 26 June 2020.

Panek, P., Alm, N., Daye, C., Edelmayer, G., Gentile, N., Magnusson, C., Mayer, P., Molenbroek, J.F., Neveryd, H., Rauhala, M., 2005. Friendly rest room project: A toilet prototype for improving the quality of life of old people and persons with disability. Assistive Technology: From Virtuality to Reality 16, 8-12.

Patel, J., 2020. Faecal shedding of SARS-CoV-2: considerations for hospital settings. Journal of Hospital Infection 105, 782-783.

Poland, G., 2020. Quote from, 'How risky is using a public restroom during the COVID-19 pandemic? Minnesota experts weigh in'. Star Tribune, July 14, 2020. At: www.startribune.com

Qu, J.Y., Xie, H.T., Zhang, M.C., 2021. Evidence of SARS-CoV-2 Transmission Through the Ocular Route. Clinical Ophthalmology 15, 687-696.

Ratnesar-Shumate, S., Williams, G., Green, B., Krause, M., Holland, B., Wood, S., Bohannon, J., Boydston, J., Freeburger, D., Hooper, I., Beck, K., Yeager, J., Altamura, L. A., Biryukov, J., Yolitz, J., Schuit, M., Wahl, V., Hevey, M., Dabisch, P., 2020. Simulated sunlight rapidly inactivates SARS-CoV-2 on surfaces. The Journal of Infectious Diseases 222, 214-222.

Razzini, K., Castrica, M., Menchetti, L., Maggi, L., Negroni, L., Orfeo, N.V., Pizzoccheri, A., Stocco, M., Muttini, S., Balzaretti, C.M., 2020. SARS-CoV-2 RNA detection in the air and on surfaces in the COVID-19 ward of a hospital in Milan, Italy. The Science of the Total Environment 742, 140540.

Ren, S.Y., Wang, W.B., Hao, Y.G., Zhang, H.R., Wang, Z.C., Chen, Y.L., Gao, R.D., 2020. Stability and infectivity of coronaviruses in inanimate environments. World Journal of Clinical Cases 8, 1391-1399.

Rodríguez, M., Palop, M. L., Seseña, S., & Rodríguez, A., 2021. Are the Portable Air Cleaners (PAC) really effective to terminate airborne SARS-CoV-2? The Science of the Total Environment 785, 147300.

Sailo, C.V., Pandey, P., Mukherjee, S., Zami, Z., Lalremruata, R., Nemi, L., Kumar, N.S., 2019. Pathogenic microbes contaminating mobile phones in hospital environment in Northeast India: incidence and antibiotic resistance. Tropical Medicine and Health 47, 59.

Salido, R. A., Morgan, S. C., Rojas, M. I., Magallanes, C. G., Marotz, C., DeHoff, P., Belda-Ferre, P., Aigner, S., Kado, D. M., Yeo, G. W., Gilbert, J. A., Laurent, L., Rohwer, F., & Knight, R, 2020. Handwashing and Detergent Treatment Greatly Reduce SARS-CoV-2 Viral Load on Halloween Candy Handled by COVID-19 Patients. mSystems 5(6), e01074-20.

Santarpia, J.L., Rivera, D.N., Herrera, V.L., Morwitzer, M.J., Creager, H.M., Santarpia, G.W., Crown, K.K., Brett-Major, D.M., Schnaubelt, E.R., Broadhurst, M.J., Lawler, J.V., Reid, S.P., Lowe, J.J., 2020. Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. Scientific Reports 10, 12732.

Santos, V.S., Gurgel, R.Q., Cuevas, L.E., Martins-Filho, P.R., 2020. Prolonged fecal shedding of SARS-CoV-2 in pediatric patients: A quantitative evidence synthesis. Journal of Pediatric Gastroenterology and Nutrition 71, 150-152.

Sassi, H.P., Reynolds, K.A., Pepper, I.L., Gerba, C.P., 2018. Evaluation of hospital-grade disinfectants on viral deposition on surfaces after toilet flushing. American Journal of Infection Control 46, 507-511.

Scottish Government, 2020. Coronavirus (COVID-19): opening public and customer toilets. https://www.gov.scot/publications/coronavirus-covid-19-public-and-customer-toilets-guidance/pages/hygiene-measures/

Shi, K.W., Huang, Y.H., Quon, H., Ou-Yang, Z.L., Wang, C., Jiang, S.C., 2021. Quantifying the risk of indoor drainage system in multi-unit apartment building as a transmission route of SARS-CoV-2. Science of the Total Environment 762, 143056.

Shimabukuro, P.M.S., Duarte, M.L., Imoto, A.M., Atallah, Á.N., Franco, E.S.B., Peccin, M.S., Taminato, M., 2020. Environmental cleaning to prevent COVID-19 infection. A rapid systematic review. Sao Paulo Medical Journal 138, 505–514.

Stanwell-Smith, R., 2010. Public toilets down the drain? Why privies are a public health concern. Public Health 124, 613-616.

Sun, J., Zhu, A., Li, H., Zheng, K., Zhuang, Z., Chen, Z., Shi, Y., Zhang, Z., Chen, S.B., Liu, X., Dai, J., Li, X., Huang, S., Huang, X., Luo, L., Wen, L., Zhuo, J., Li, Y., Wang, Y., Zhang, L., Li, Y.

M., 2020. Isolation of infectious SARS-CoV-2 from urine of a COVID-19 patient. Emerging Microbes & Infections 9, 991–993.

Sun, S., Han, J., 2020. Open defecation and squat toilets, an overlooked risk of fecal transmission of COVID-19 and other pathogens in developing communities. Environmental Chemistry Letters 1–9. Advance online publication.

Tang, J. W., Bahnfleth, W. P., Bluyssen, P. M., Buonanno, G., Jimenez, J. L., Kurnitski, J., Li, Y., Miller, S., Sekhar, C., Morawska, L., Marr, L. C., Melikov, A. K., Nazaroff, W. W., Nielsen, P. V., Tellier, R., Wargocki, P., & Dancer, S. J. (2021). Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2). The Journal of Hospital Infection 110, 89–96.

Uchino, K., Miyoshi, T., Matsuo, M., Ikeda, Y., Yoshida, Y., Teranaka, Y., Sugimoto, M., Sasaki, Y., Shibata, H., Fujii, F., Tanaka, T., 2006. Combined genogroup I and II norovirus infection at a nursery. Japanese Journal of Infectious Diseases 59, 270–272.

van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., Tamin, A., Harcourt, J.L., Thornburg, N.J., Gerber, S.I., Lloyd-Smith, J.O., de Wit, E., Munster, V.J., 2020. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. New England Journal of Medicine 382, 1564-1567.

Verani, M., Bigazzi, R., Carducci, A., 2014. Viral contamination of aerosol and surfaces through toilet use in health care and other settings. America Journal of Infection Control 42, 758-62.

Wan, B., Zhang, X., Luo, D., Zhang, T., Chen, X., Yao, Y., Zhao, X., Lei, L., Liu, C., Zhao, W., Zhou, L., Ge, Y., Mao, H., Liu, S., Chen, J., Cheng, X., Zhao, J., Sui, G., 2021. On-site analysis of COVID-19 on the surfaces in wards. The Science of the Total Environment 753, 141758.

Wang, J.X., Li, Y.Y, Liu, X.D., Cao, X., 2020. Virus transmission from urinals. Physics of Fluids 32, 081703.

Wang, W., Xu, Y., Gao, R., Lu, R., Han, K., Wu, G., 2020. Detection of SARS-CoV-2 in different types of clinical specimens. JAMA 323, 1843-1844.

WHO, 2020. Considerations for public health and social measures in the workplace in the context of COVID-19: annex to considerations in adjusting public health and social measures in the context of COVID-19. https://www.who.int/publications/i/item/considerations-for-public-health-and-social-measures-in-the-workplace-in-the-context-of-covid-19

Widdowson, M.A., Glass, R., Monroe, S., Beard, R.S., Bateman, J. W., Lurie, P., Johnson, C., 2005. Probable transmission of norovirus on an airplane. JAMA 293, 1859-1860.

Wölfel, R., Corman, V. M., Guggemos, W., Seilmaier, M., Zange, S., Müller, M. A., Niemeyer, D., Jones, T. C., Vollmar, P., Rothe, C., Hoelscher, M., Bleicker, T., Brünink, S., Schneider, J., Ehmann, R., Zwirglmaier, K., Drosten, C., Wendtner, C., 2020. Virological assessment of hospitalized patients with COVID-2019. Nature 581, 465–469.

Wong, M.C., Huang, J., Lai, C., Ng, R., Chan, F.K.L., Chan, P.K.S., 2020. Detection of SARS-CoV-2 RNA in fecal specimens of patients with confirmed COVID-19: A meta-analysis. Journal of Infection 81, e31-e38.

Wu, D., Lam, T.P., Chan, H.Y., Lam, K., Zhou, X.D., Xu, J.Y., Sun, K.S., Ho, P.L., 2019. A mixed-methods study on toilet hygiene practices among Chinese in Hong Kong. BMC Public Health 19, 1-8.

Wu, Y., Guo, C., Tang, L., Hong, Z., Zhou, J., Dong, X., Yin, H., Xiao, Q., Tang, Y., Qu, X., Kuang, L., Fang, X., Mishra, N., Lu, J., Shan, H., Jiang, G., Huang, X., 2020. Prolonged presence of SARS-CoV-2 viral RNA in faecal samples. The Lancet Gastroenterology & Hepatology 5, 434–435.

Xiao, F., Tang, M., Zheng, X., Liu, Y., Li, X., Shan, H., 2020a. Evidence for gastrointestinal infection of SARS-CoV-2. Gastroenterology 158, 1831-1833.e3.

Xiao, F., Sun, J., Xu, Y., Li, F., Huang, X., Li, H., Zhao, J., Huang, J., Zhao, J., 2020b. Infectious SARS-CoV-2 in feces of patient with severe COVID-19. Emerging and Infectious Diseases 26, 1920-1922.

Xiao, S.L., Li, Y.G., Lei, H., Lin, C.H., Norris, S.L., Yang, X.Y., Zhao, P.C., 2018. Characterizing dynamic transmission of contaminants on a surface touch network. Building and Environment 129, 107-116.

Xiao, S., Tang, J. W., Li, Y., 2017. Airborne or fomite transmission for norovirus? A case study revisited. International Journal of Environmental Research and Public Health 14, 1571.

Xu, D., Zhang, Z., Jin, L., Chu, F., Mao, Y., Wang, H., 2005. Persistent shedding of viable SARS-CoV in urine and stool of SARS patients during the convalescent phase. European Journal of Clinical Microbiology & Infectious Diseases 24, 165–171.

Xu, Y., Li, X., Zhu, B., Liang, H., Fang, C., Gong, Y., Guo, Q., Sun, X., Zhao, D., Shen, J., Zhang, H., Liu, H., Xia, H., Tang, J., Zhang, K., Gong, S., 2020. Characteristics of pediatric SARS-CoV-2 infection and potential evidence for persistent fecal viral shedding. Nature Medicine 26, 502-505.

Ye, G., Lin, H., Chen, S., Wang, S., Zeng, Z., Wang, W., Zhang, S., Rebmann, T., Li, Y., Pan, Z., Yang, Z., Wang, Y., Wang, F., Qian, Z., Wang, X., 2020. Environmental contamination of SARS-CoV-2 in healthcare premises. The Journal of Infection 81, e1–e5.

Yuan, J., Chen, Z., Gong, C., Liu, H., Li, B., Li, K., Chen, X., Xu, C., Jing, Q., Liu, G., Qin, P., Liu, Y., Zhong, Y., Huang, L., Zhu, B.P., Yang, Z., 2020. Sewage as a possible transmission vehicle during a Coronavirus Disease 2019 outbreak in a densely populated community: Guangzhou, China, April 2020. Clinical Infectious Diseases ciaa1494 Advance online publication.

Yu, I.T., Li, Y., Wong, T.W., Tam, W., Chan, A.T., Lee, J.H., Leung, D.Y., Ho, T., 2004. Evidence of airborne transmission of the severe acute respiratory syndrome virus. New England Journal of Medicine 350, 1731-1739.

Zhang, H., Kang, Z., Gong, H., Xu, D., Wang, J., Li, Z., 2020. The digestive system is a potential route of 2019-nCov infection: a bioinformatics analysis based on single-cell transcriptomes. BioRxiv. 2020, biorxiv.org. https://www.biorxiv.org/content/10.1101/2020.01.30.927806v1.abstract

Zhang, X.S., Duchaine, C., 2020. SARS-CoV-2 and health care worker protection in low-risk settings: A review of modes of transmission and a novel airborne model involving inhalable particles. Clin Microbiology Reviews 34, e00184-20.

Zhang, Y., Chen, C., Song, Y., Zhu, S., Wang, D., Zhang, H., Han, G., Weng, Y., Xu, J., Xu, J., Yu, P., Jiang, W., Yang, X., Lang, Z., Yan, D., Wang, Y., Song, J., Gao, G. F., Wu, G., Xu, W., 2020a. Excretion of SARS-CoV-2 through faecal specimens. Emerging Microbes & Infections 9, 2501–2508.

Zhang, Y., Chen, C., Zhu, S., Shu, C, et al., 2020b. Isolation of 2019-nCoV from a stool specimen of a laboratory confirmed case of the coronavirus disease 2019 (COVID-19). China CDC Weekly 2, 123-124.

Zhao, P., Zhang, N., Li, Y., 2020. A comparison of infection venues of Covid-19 case clusters in North East China. International Journal of Environmental Research and Public Health 17, 3955.