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

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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.

GRAPHICAL ABSTRACT

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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.

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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, 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 (Chen et al., 2020; Gu et al., 2020; He et al., 2020; W. Wang 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; Chen et al., 2020; Gupta et al., 2020; Jones 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 et al., 2020; W. Wang et al., 2020; Wong et al., 2020; Wu et al., 2020; Xu et al., 2005; Xu 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 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 (Amirian, 2020). However, viable virus has been isolated and confirmed from patient stool and urinary samples (Jeong et al., 2020; Jones et al., 2020; Wong et al., 2020; W. Wang et al., 2020; Xiao et al., 2020a; Xiao et al., 2020b; H. Zhang et al., 2020; Zhang et al., 2020a; Zhang 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 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 (Fig. 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 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; J.X. Wang 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

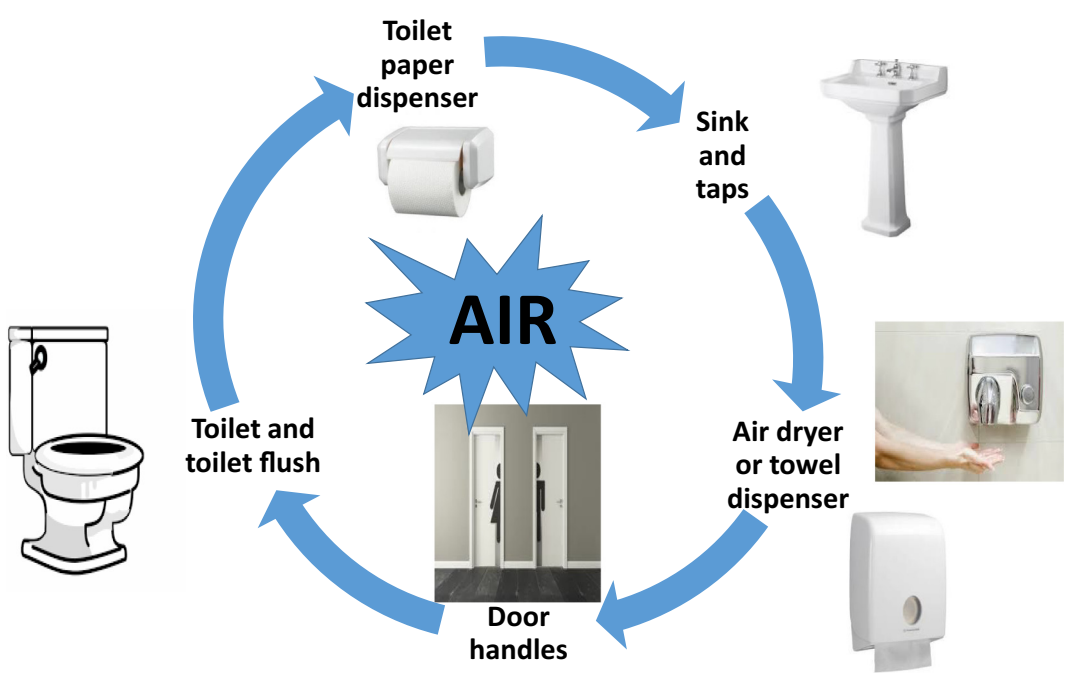

Fig. 1. Main transmission risks of SARS-CoV-2 for users of public toilets.

(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 (Fig. 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 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 Hazma, 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 (Lam et al., 2021). 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 (Fig. 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., 2021; 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., Lam et al., 2021; 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 1)

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.

Fig. 2. Surface contamination in a bathroom.

Table 1
How to stay safe from COVID-19 in a public toilet.

How to stay safe from COVID-19 in a public toilet
1. Wear a face mask
2. Put used toilet paper into the toilet bowl or waste bin and not on the floor
3. If there is a toilet lid, put it down before flushing
4. Wash your hands with running water and soap or apply hand disinfectant
5. Do not spit into wash basins
6. Dry your hands if washing, preferably with disposable towels, or use the dryer; don't return to the toilet cubicle for toilet paper to dry your hands
7. Place all disposable towels in waste bins
8. Help others to wash and dry hands if necessary, e.g. children
9. Do not use phones or other mobile devices in the toilet
10. Spend as little time in the toilet as possible
11. Hold the door open for others on entrance or exit

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 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; Lam et al., 2021). 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 1000 ppm 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 Brutto 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).

3.3.9. 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 Jurnaa, 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 suggests 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 (Chen et al., 2020a).

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 Brutto et al., 2020a; Del Brutto et al., 2020b). A widely

neglected aspect of virus containment is that a major part of the population in developing regions does not have access to private, clean sanitary facilities (Mallory et al., 2020; Sun and Han, 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 practising 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 and Han, 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 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 (Wölfel 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 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.

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.

Declaration of competing interest

There are no relevant declarations of interest for any of the authors of 'What is the risk of acquiring SARS-CoV-2 from the use of public toilets?'

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