UNIVERSITY OF BRISTOL

RESEARCH ARTICLE

Environmental screening for SARS-CoV-2 in long term care facilities: lessons from a pilot study [version 1; peer review: awaiting peer review]

Rachel Kwiatkowska [ID][1-3], Nicola Yaxley[4], Ginny Moore [ID][4], Allan Bennett[4], Matthew Donati[5,6], Nicola Love[7], Roberto Vivancos[8,9], Matthew Hickman[2,3], Derren R Ready[1,3,10]

[1]Field Service, National Infection Service, Public Health England, Bristol, UK
[2]Population Health Sciences, University of Bristol, Bristol, UK
[3]NIHR Health Protection Research Unit in Behavioural Science and Evaluation, University of Bristol, Bristol, UK
[4]National Infection Service, Public Health England, Porton Down, Salisbury, UK
[5]Severn Infection Sciences, North Bristol NHS Trust, Bristol, UK
[6]Public Health England South West Regional Laboratory, National Infection Service, Bristol, UK
[7]Field Service, National Infection Service, Public Health England, Newcastle, UK
[8]NIHR Health Protection Research Unit in Gastrointestinal Infections, University of Liverpool, Liverpool, UK
[9]Field Service, National Infection Service, Public Health England, Liverpool, UK
[10]Eastman Dental Institute, University College London, London, UK

Open Peer Review

Reviewer Status *AWAITING PEER REVIEW*

Any reports and responses or comments on the article can be found at the end of the article.

Abstract

Background: The SARS-CoV-2 pandemic has highlighted the risk of infection transmission in long-term care facilities (LTCF) and the vulnerability of resident populations. It is essential to understand the environmental spread of the virus and risk of indirect transmission to inform Infection Prevention and Control (IPC) measures in these settings.

Methods: Upon notification of SARS-CoV-2 outbreaks, LTCF within a local authority in the South West of England were approached to take part in this pilot study. Investigators visited to swab common touch-points and elevated 'non-touch' surfaces and samples were analysed for presence of SARS-CoV-2 genetic material (RNA). Data were collected regarding LTCF infrastructure, staff behaviours, clinical and epidemiological risk factors for infection (staff and residents), and IPC measures.

Criteria for success were: recruitment of three LTCF; detection of SARS-COV-2 RNA; variation in proportion of SARS-CoV-2 positive surfaces by sampling zone; potential to assess infection risk from SARS-CoV-2 positive surfaces.

Results: Three LTCFs were recruited, ranging in size and resident demographics. Outbreaks lasted 63, 50 and 30 days with resident attack rates of 53%, 40% and 8%, respectively. The proportion of

sample sites on which SARS-CoV-2 was detected was highest in rooms occupied by infected residents and varied elsewhere in the LTCF, with low levels in a facility implementing enhanced IPC measures. The heterogeneity of settings and difficulty obtaining data made it difficult to assess association between environmental contamination and infection. Elevated surfaces were more likely to test positive for SARS-CoV-2 RNA than common touch-points.

Conclusions: SARS-CoV-2 RNA can be detected in a variety of LTCF outbreak settings. We identified variation in environmental spread which could be associated with implementation of IPC measures, though we were unable to assess the impact on infection risk. Sampling elevated surfaces could add to ongoing public health surveillance for SARS-CoV-2 and other airborne pathogens in LTCF.

Keywords

infection control; infectious disease transmission; environmental exposure; fomites; disease outbreaks; long-term care; epidemiologic methods

Corresponding author: Rachel Kwiatkowska (rachel.kwiatkowska@bristol.ac.uk)

Author roles: Kwiatkowska R: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Writing – Original Draft Preparation, Writing – Review & Editing; **Yaxley N**: Formal Analysis, Methodology, Writing – Review & Editing; **Moore G**: Conceptualization, Formal Analysis, Investigation, Methodology, Resources, Supervision, Writing – Review & Editing; **Bennett A**: Conceptualization, Methodology, Supervision, Writing – Review & Editing; **Donati M**: Methodology, Resources, Writing – Review & Editing; **Love N**: Methodology, Resources, Writing – Review & Editing; **Vivancos R**: Methodology, Supervision, Writing – Review & Editing; **Hickman M**: Methodology, Supervision, Writing – Review & Editing; **Ready DR**: Conceptualization, Investigation, Methodology, Resources, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Introduction

Long term care facilities (LTCF) are inadvertently ideal environments for the spread of pathogens. (Strausbaugh *et al.*, 2003) Residents are often susceptible to infection or colonisation, and in frequent and close contact with staff who have links to the wider community. Outbreaks of infectious diseases are common in these settings (Inns *et al.*, 2017; Inns *et al.*, 2019) and the coronavirus 2019 (COVID-19) pandemic, caused by SARS-CoV-2 coronavirus, has highlighted the vulnerability of people in LTCF to infectious disease threats: there were an estimated 29,542 excess deaths among LTCF residents over the first 23 weeks of the epidemic in England. (Morciano *et al.*, 2021)

If detected early enough transmission of pathogens within the LTCF can be curbed, (Inns *et al.*, 2018) however SARS-CoV-2 infections are often asymptomatic or paucisymptomatic leading to large outbreaks. Regular testing of residents and staff helps identify cases early but is resource-intensive and unpleasant for frail individuals, so non-invasive surveillance strategies may be more sustainable in the long term. Swabbing touch-points and elevated surfaces (which airborne pathogens will settle on) could provide early warning of infection as well as providing insights into how the virus is transmitted, which can inform infection prevention and control (IPC) measures. According to a World Health Organization scientific brief on transmission of SARS-CoV-2 (2020), direct (droplet) transmission and indirect spread via fomites (contaminated surfaces) and long-distance aerosols are thought to occur; however there is no conclusive evidence for indirect transmission in LTCF. (Ben-Shmuel *et al.*, 2020; Greenhalgh *et al.*, 2021; Ong *et al.*, 2020; Ye *et al.*, 2020)

COVID-19: Detecting Indirect Transmission in Facilities for Enhanced Care sTudy (COVID-19: DISinFECT) aims to investigate the role of indirect transmission of SARS-CoV-2 in LTCF and evaluate the potential for environmental surveillance to inform IPC measures. We present findings from a pilot conducted between 14th January and 28th March 2021, during the second epidemic wave in South West England.

Methods

DISinFECT methods are detailed in the protocol which can be accessed online. (Kwiatkowska & Ready, 2021) LTCFs were eligible for inclusion if they provided residential care for older adults (>65 years), were within the boundaries of a selected local authority in the Public Health England (PHE) South West region, and experienced a COVID-19 outbreak, defined as two or more laboratory-confirmed cases among staff and/or residents within a 14-day period.

Recruitment

On notification of an outbreak, investigators contacted the LTCF manager with information about DISinFECT and offered environmental sampling as part of outbreak management. If managers expressed an interest they were asked to complete a consent form permitting the study team to conduct telephone interviews, collect information from care home records, sample the care home environment and approach residents and staff for involvement. Prior to the sampling visit, residents and staff were provided with written and pictorial leaflets describing the purpose of the investigations, sampling procedures and how their information would be processed. Each of the residents selected for sampling was consulted to make sure they understood this information and were happy to provide samples. Sampling was not carried out if the individual lacked capacity to complete a consent form. Staff were asked for consent to participate prior to accessing the electronic questionnaire.

Sampling

Settings varied in size and layout but sampling was done systematically, with a focus on common touch points (for example: door handles, light switches, television remote controls) and elevated surfaces onto which airborne virus might settle (for example: door sills, tops of wall-mounted cabinets).

Within each home, sampling sites were categorised in to three 'zones': 1) rooms occupied by residents isolating with active SARS-CoV-2 infection, or equipment used by them, 2) areas/equipment used by both staff and residents such as lounges and dining areas, shared kitchen equipment, and 3) staff-only areas/equipment such as offices, recreation areas, and key cabinets (see Figure 1). Surfaces were sampled using wetted flocked swabs and sponges, and wetted swabs were also used to swab the fingertips of residents in isolation rooms. All samples were transported to a public health laboratory specialising in aerobiology, biocontainment and biosafety measures.

The full DISinFECT protocol includes sampling stool and saliva from resident cases and air and wastewater sampling from the facility but for logistical reasons, stool and saliva could not be taken during this pilot. Likewise, no air sampling was conducted, and wastewater was collected from only one facility; results will be reported separately.

Laboratory analysis

Each sample was analysed in duplicate using a Reverse Transcription Polymerase Chain Reaction (RT-PCR) assay targeting both the N gene and the ORF1ab gene of SARS-CoV-2 (Viasure, CerTest Biotec, Zaragoza). Results were reported in cycle threshold (Ct) numbers. A sample was classified as 'positive' for SARS-CoV-2 if amplification of one or both targets was detected in both duplicates; 'suspect' if detected in only one duplicate and 'negative' if no amplification was detected for either gene target (Ct cut-off was 39). RT-PCR was repeated (in duplicate) for 'suspect' samples and samples with an internal control Ct standard deviation of >0.5. If repeat RT-PCR detected amplification of a gene target in both duplicates then the 'suspect' sample was reclassified as 'positive'; otherwise the sample remained 'suspect'.

Where possible, diagnostic isolates were sent for whole genome sequencing (WGS) to identify SARS-CoV-2 variants and mutations of interest/concern.
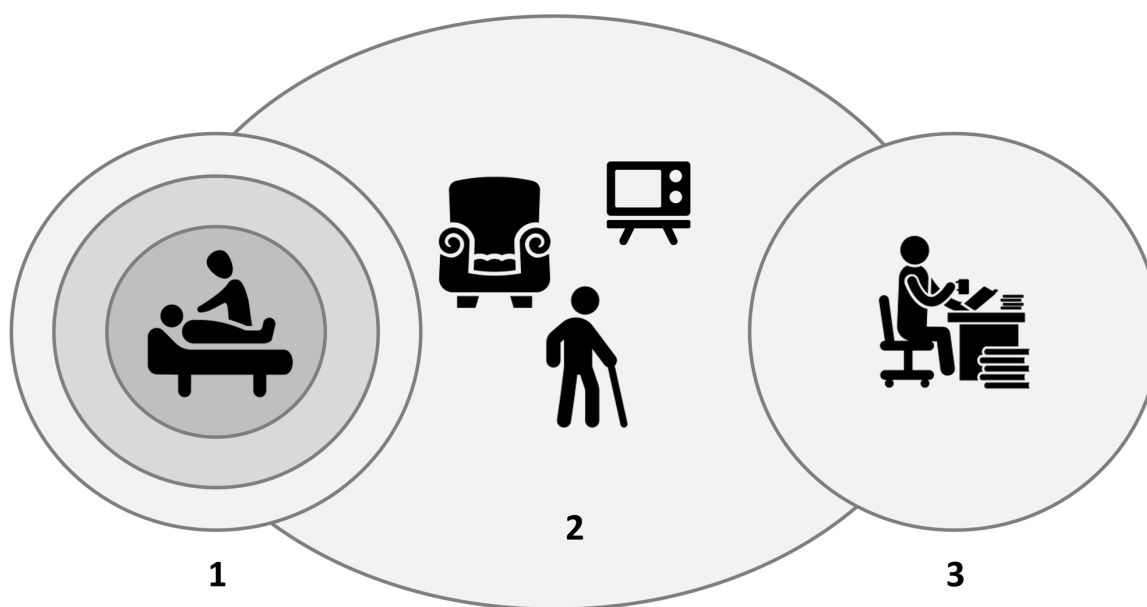
Figure 1. Sampling zones in care homes recruited to DISinFECT: 1) rooms/ equipment used mainly by residents, 2) areas/equipment shared by both residents and staff, and 3) staff-only areas/ equipment. Image icons by Delwar Hossain and ProSymbols, sourced from https://thenounproject.com/.

Epidemiological data collection

In addition to sampling, the study team recorded details of LTCF layout, cleaning and IPC measures, and staff and resident behaviours. Clinical test results (nasopharyngeal swabs analysed with PCR) were obtained from the regional public health laboratory and LTCF managers provided additional information about clinical case notifications, resident risk factors for infection and IPC measures. Finally, staff members were sent an electronic questionnaire asking questions about exposures and risk factors for infection.

Criteria for success in the pilot are presented in Box 1.

Box 1. DISinFECT pilot criteria for success

a) Recruitment of three LTCF and consent to participate from at least one resident per facility;

b) Detection of SARS-CoV-2 RNA from surface sampling;

c) Variation by sampling zone in the proportion of sample sites testing positive for SARS-CoV-2 RNA;

d) Potential to assess transmission risk from environmental contamination, in the context of individual risk factors for infection.

Ethical considerations

These investigations were carried out as part of a public health response to the SARS-CoV-2 pandemic. Ethical approval was granted on 14th January 2021 by the Public Health England Research Ethics and Governance Group (PHE REGG: RD 415).

Results

Four LTCFs were approached on notification of an outbreak: one declined to participate on the grounds that they did not have capacity to consider the study information or arrange for residents to be consulted. Three LTCFs were sampled between 2nd February and 10th March 2021 and a total of 84 environmental swabs were taken (56 from common touch points, 28 from elevated sites). One home had two sampling visits, 14 days apart. For simplicity, we have labelled the homes A, B and C in order of sampling dates. Table 1 contains the full list of sampling sites.

Setting and population

LTCF sizes ranged in size: there were 40 beds in facility A, which was a self-contained unit within an 80-bedded LTCF, 16 beds in facility B and 13 beds in facility C. The number of occupants was 30 (A), 15 (B) and 12 (C) on the date of onset of the first case. Facility A was a short stay residential unit with clients aged between 55 and 98 years; facility B a residential home for older adults (65 and over) with and without dementia; facility C a residential home for adults with learning difficulties aged between 35 and 88 years. All residents were included in the epidemiological analysis, regardless of age. All residents slept in single occupancy rooms; residents in facilities A and C all had private bathrooms and 13/16 rooms in facility B were en-suite. Characteristics of the three facilities are summarised in Table 2.

Outbreak trajectory and control measures

SARS-CoV-2 attack rates among residents were highest in facility A: 16/30 (53%, of which 15/16 (94%) were symptomatic),

Table 1. Sampling sites and SARS-CoV-2 RNA positivity by facility.

Facility A: sampling sites	*	PCR† for SARS-CoV-2	Facility B: sampling sites	*	PCR† for SARS-CoV-2	2nd visit PCR† result	Facility C: sampling sites	*	PCR† for SARS-CoV-2
Female staff changing room			*Staff toilet*				*Staff office*		
1. Top of lockers (next to door)	E	Negative	1. Air vent/ extractor	E	Negative	Negative	1. Top of key cupboard	E	Negative
2. Toilet door: inside handle and lock	T	Negative	2. Soap dispenser lever	T	Negative	Negative	2. Computer mouse	T	Negative
3. Air vent/ extractor (toilet)	E	Negative	3. Door ledge (outer)	E	Positive (Ct N 36.47 ± 0.46)	Negative	3. Top of message board	E	Negative
4. Bench top	T	Negative	*Manager's office*				4. Telephone receiver	T	Negative
5. Soap dispenser lever	T	Negative (Ct N 39.06)	4. Computer mouse	T	Negative	Negative	*Shared toilet (staff/ residents)*		
Dining room (staff)			*Laundry room*				5. Air vent/ extractor	E	Negative
6. Top of TV	E	Negative	5. Air vent/ extractor	E	Positive (Ct N 37.43 ± 0.01)	Negative	6. Soap dispenser lever	T	Negative
7. Top of trolley (for lunch trays)	E	Negative	6. Glove box (size small)	T	Negative	N/A	*Reception area*		
8. Radio dials	T	Negative	*Shared toilet (staff/ residents)*				7. Front door keypad (inside)	T	Negative
Sluice room			7. Toilet booster handles	T	Negative	Negative	8. Top of kitchen door frame (outside)	E	Negative
9. Code pad (door exterior)	T	Negative	8. Air vent/ extractor	E	Positive (Ct N 36.22 ± 0.35)	Negative	*Staff break area*		
Breakout room (staff)			9. Toilet booster underside	T	Negative	Negative	9. Air vent/ extractor	E	Negative
10. Chair arms	T	Negative	*Dining area (residents & staff)*				10. Fire exit sign	E	Negative
11. Air vent/ extractor	E	Negative	10. Tablecloth	T	Suspect (Ct N 36.99)	Negative	11. Door handle (exit to reception)	T	Negative
12. Light switch	T	Negative	11. Tea trolley handles	T	Negative	Negative	12. Bannister	T	Negative
Corridor			12. Armchair handles	T	Negative	Negative	*Lounge/ shared kitchen area*		
13. UV cabinet handle	T	Negative	13. Top of picture frame	E	Suspect (Ct N 37.05)	Negative	13. Top of kitchen hatch	E	Negative
Photocopier room			14. TV remote control	T	Positive (Ct N 37.54 ± 0.12)	Negative	14. Chair arms	T	Negative
14. Photocopier digital pad	T	Negative	*Bedroom/ bathroom*				15. Kettle handle & switch	T	Negative
Bedroom/ bathroom #1			15. Top of wardrobe	E	Positive (Ct N 33.80 ± 0.18)	Positive (Ct N 35.25 ± 0.35)	16. Microwave handle & dial	T	Negative
15. Bedrails (unoccupied)	T	Suspect (Ct N 37.43)	16. Fingertips (L hand)	-	Negative	Negative	17. Air vent/ extractor	E	Negative
16. Fingertips (R hand)	-	Negative	17. Fingertips (R hand)	-	Negative		*Corridor*		

Facility A: sampling sites	*	PCR† for SARS-CoV-2	Facility B: sampling sites	*	PCR† for SARS-CoV-2	2nd visit PCR† result	Facility C: sampling sites	*	PCR† for SARS-CoV-2
17. Hoist handle	T	Negative	18. TV remote	T	Positive (Ct N 31.75 ± 0.06)	Negative	18. Glove box – size small	T	Negative
18. Chair seat (occupied)	T	Negative	19. Tabletop (swab)	T	Negative	Negative	19. Lip of PPE cabinet	T	Negative
19. Air vent/ extractor (bedroom)	E	Negative	20. Tabletop (sponge)	T	Positive (Ct N 36.71 ± 0.75)		20. Air vent/ extractor	E	Negative
20. Catheter stand (bathroom)	T	Negative	21. Chair arms	T	Positive (Ct N 34.91 ± 0.02)	Negative	21. Hand rail	T	Negative
Bedroom/ bathroom #2			22. Walking frame handles	T	Positive (Ct N 34.97 ± 0.40)	Negative	*Bedroom/ bathroom*		
21. Bed remote control (occupied)	T	Positive (Ct N 37.59 ± 0.76)	23. Bed head	T	Suspect (Ct N 37.58)	Suspect (Ct N 37.37)	22. Fingertips (R hand)	-	Negative
22. Air vent/ extractor (bedroom)	E	Negative	24. Wardrobe handle	T	Suspect (Ct N 37.50)		23. Fingertips (L hand)	-	Negative
23. TV control (in use)	T	Positive (Ct N 35.23 ± 0.34)	25. Bathroom door handle (outer)	T	Suspect (Ct N 37.40)	Negative	24. Table top	T	Negative
24. Top of TV	E	Positive (Ct N 35.66 ± 0.41)	26. Bathroom door handle (inner)	T	Suspect (Ct N 37.02)		25. Chair arms	T	Negative
25. Top of clock	E	Negative	27. Air vent/ extractor (bathroom)	E	Positive (Ct N 34.64 ± 0.00)	Positive (Ct N 38.29 ± 0.11)	26. Bed remote control	T	Negative
26. Commode seat (bathroom)	T	Positive (Ct N 37.78 ± 0.21)	28. Toilet seat booster	T	Negative	Negative	27. Bed head	T	Negative
27. Fingertips (both hands)	-	Negative	*Corridor*				28. Walking frame handles	T	Negative
28. Top of light above bathroom sink	E	Positive (Ct N 36.23 ± 0.90)	29. Bannister outside laundry	T	Negative		29. Curtain pole	E	Negative
29. Oxygen saturations probe (outside room)	T	Positive (Ct N 35.97 ± 0.03)	*Staff office*				30. Wheelbarrow handles	T	Negative
			30. Top of key cabinet	E	Positive (Ct N 37.76 ± 0.30)		31. Air vent/ extractor (bathroom)	E	Suspect (Ct N 37.75)
							32. Hoist rail (bathroom)	T	Negative
							33. Toilet handle	T	Negative

* Designated common touch point (T) or elevated site (E)

† Samples are analysed in duplicate: a positive result means the target gene is detected in both replicates (reported as Cycle threshold (Ct) number with 95% confidence intervals). If the target gene is identified in only one sample, it is reported as suspect. Ct values reported for N gene target: the higher the Ct value, the lower the concentration of viral RNA. Limit of detection set at Ct 39.

NB not all sites were re-sampled on the second visit to facility B (labelled N/A), and some sample sites were combined (indicated by merged cells in the table).

Table 2. Characteristics of DISinFECT pilot LTCFs and resident populations.

ID	CQC[φ] rating	No. residents/ no. beds (% occupancy*)	No. floors	Private/ shared bathroom	Care provision	Agency staff	Dependent/ independent	Age range (years)	Walk with purpose[†]	Prevalence comorbidities[ψ]
A	O	30/40 (75.0%)	1	Private	Residential: short stay	Yes - block	Mixed	55–98	No	23/30 (76.7%)
B	G	15/16 (93.8%)	2	Mixed	Residential: older adults (+/- dementia)	Yes	Mixed	71–97	Yes	13/15 (86.7%)
C	G	12/13 (92.3%)	2	Private	Residential: adults with Learning Difficulties	No	Mixed	35–88	Yes	data unavailable

*registered occupancy at time of sampling visit; [φ]CQC = Care Quality Commission, O = Outstanding, G = Good; [†]one or more resident unable to adhere to self-isolation within private room; [ψ]presence of one or more chronic condition (overweight/obese; chronic respiratory disease; chronic heart disease; dementia; diabetes; hypertension; immunocompromised/ cancer) among registered occupants over the course of the outbreak; Dependent/ independent relates to resident mobility.

followed by facility B: 6/15 (40%, of which 3/6 (50%) symptomatic). Only one resident tested positive in LTCF C (8%): this individual was asymptomatic and had received the first vaccine dose four weeks beforehand. They also had a history of laboratory-confirmed COVID-19 a year previously. A repeat sample taken 10 days after the most recent diagnosis was PCR negative for SARS-CoV-2, nonetheless the individual remained in isolation for 14 days as a precaution. Non-agency staff attack rates were also highest in facility A: 16/60 (27%) followed by facility B: 4/22 (18%) and C: 1/35 (3%). Numbers of agency staff were not available. Duration of outbreak (calculated from the date of first illness onset to 28 days after onset of the final case) was 63, 50 and 30 days for facilities A, B and C respectively. Facilities A and B had residents admitted to hospital (n=5 symptomatic cases and n=3 of which one was symptomatic, respectively). Sadly there were COVID-19-related deaths among residents (facility A: n=2, both receiving end-of-life care, one hospitalised; facility B: n=1, hospitalised). Figure 2 illustrates outbreak trajectories in facilities A and B.

Only facility A (the short stay unit) was effectively isolating all residents within their rooms at the time of the sampling visit. Facilities A and C were cohorting staff, allocating them to work exclusively with SARS-CoV-2 positive residents or with SARS-CoV-2 negative residents, and the infected resident in facility C was isolated on a separate floor to the rest of the residents. Staff in all three facilities underwent daily lateral flow (point-of-care) antigen tests for a minimum of five days followed by routine twice weekly testing, as well as weekly PCR testing for SARS-CoV-2 according to national guidance for testing in care homes. All homes were closed to visitors and new admissions for the duration of the outbreak, except for end of life visits in facility A. Table 3 summarises outbreak metrics and control measures.

All homes adopted enhanced cleaning protocols in response to the COVID-19 epidemic, with increased frequency and a focus on common touch points. In addition, facility A provided fresh uniforms for staff at the beginning of each shift (laundered on site) and had installed a UV cabinet for treating phones and keys prior to handover. All LTCF managers stated that personal protective equipment (PPE) was available to staff in line with national guidance.

In facilities B and C, 100% of residents had received the first dose of a COVID-19 vaccine more than two weeks prior to outbreak onset. In facility A, 83% of residents had received the first dose of vaccine but just four days before onset of the outbreak. In facility A, 80% of non-agency staff were reported to have received a vaccine, though these figures related to the wider facility and exact vaccination dates were not provided. Facility B reported 55% and facility C 96% of non-agency staff vaccinated with at least one dose more than two weeks prior to the outbreak.

Observations
Facility A was a modern building with spacious, uncluttered rooms of a uniform layout. Signage was in place to remind staff to clean surfaces and socially distance, and the sampling team observed good adherence to PPE donning and doffing protocols. All residents were isolated in their rooms, and staff wore 'scrubs'.

Facility B was an older building, once a large house. Residents' rooms were small and somewhat cluttered with several sampling sites visibly soiled. Several residents were observed using the dining area and lounge (unmasked); staff wore their own clothing.

Facility C was a relatively modern building; rooms were small but uncluttered with fewer soft furnishings than LTCFs
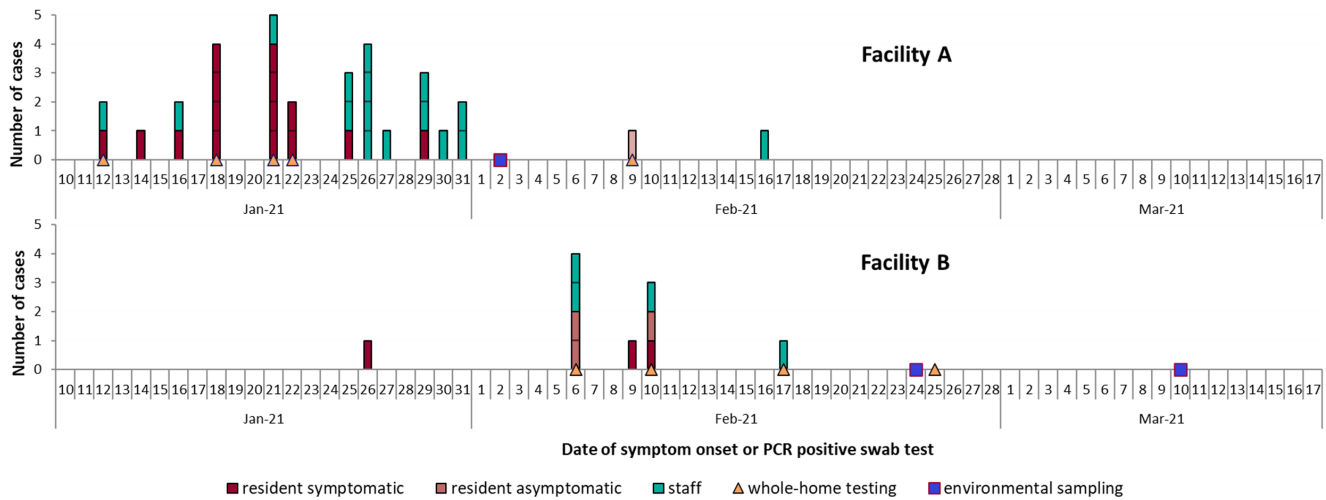
Figure 2. Epidemic curves illustrating case onset in LTCFs A (30 residents) and B (15 residents). Community case rates peaked at the end of December during the second wave of the UK epidemic.

A and B. Two residents were observed walking with purpose (unmasked), accompanied by carers; staff wore their own clothing.

Proportion of sites testing positive and distribution of SARS-CoV-2 RNA

Facility B had the highest proportion of sampling sites testing positive/ suspect for SARS-CoV-2 RNA (PCR positive on one or both duplicates): 17/28 (61%), followed by LTCF A: 6/27 (22%). In LTCF C, all environmental swabs were negative for SARS-CoV-2 except for one suspect positive from an air extractor in the index case's bathroom: positivity 1/31 (3%).

A repeat visit to facility B two weeks after the initial sampling visit yielded a much lower proportion of SARS-CoV-2 positive/ suspect sampling sites (4/19; 21%).

Concentrations of SARS-CoV-2 RNA, as inferred from Ct values, were very low for all positive and suspect samples. The lowest Ct value found was 31.8, and only four samples had a Ct value of below 35. Amplification was below the limit of detection in two samples (see Table 1).

SARS-CoV-2 positive/ suspect surfaces were most common in zone 1 (rooms occupied by residents with active SARS-CoV-2 infection, and equipment used by them), as illustrated in Figure 3.

Proportion of SARS-CoV-2 positive sites in proximity to a COVID-19 case

Within zone 1, there was significant variation in the proportion of sample sites testing positive/ suspect for SARS-CoV-2 RNA. For example, in facility A two residents' rooms were sampled: in the first room, 1/5 (20%) of sample sites was 'suspect positive' for SARS-CoV-2 RNA and in the second room 6/8

(75%) of sample sites tested positive. Both rooms were similar in size and layout, and subject to the same cleaning protocols. The first room was occupied by an individual who was bed/chair bound, and who had tested positive for the virus 11 days previously and had fever and a slight cough. The occupant of the second room spent much of their time confined to bed, though was mobile with a wheelchair. This individual tested positive for SARS-CoV-2 infection seven days prior to the visit and had a cough. Figure 4 shows the environmental sample site positivity in relation to the time from onset of illness for the room occupant.

Proportion of common touch points testing positive for SARS-CoV-2 vs elevated surfaces

Overall, the proportion of common touch points testing positive/ suspect for SARS-CoV-2 RNA (15/56; 27%) was slightly lower than the proportion of sites testing positive/ suspect (10/28; 36%), though this was not consistent between LTCFs (see Table 4). Where the proportion of positive common touch points was highest (facility B), a large proportion of elevated sites were also tested positive/ suspect for SARS-CoV-2 RNA.

Fingertip samples
None of the swabs taken from fingertips of residents with confirmed COVID-19 were PCR positive for SARS-CoV-2 RNA.

WGS of clinical isolates
A small number of outbreak isolates were sequenced by the COVID-19 Genomics UK Consortium (COG-UK) (facility A: n=3; facility B: n=3). All were identified as B.1.1.7 (VOC-202012/01), with no E484K substitution detected.

Staff survey results
Response rates to the electronic staff survey were poor: 11/60 (18%) from facility A, 6/22 (27%) from facility B and 0/35

Table 3. Outbreak metrics and control measures for DISinFECT pilot LTCFs.

ID	Outbreak metrics					Infection Prevention & Control						COVID-19 vaccine	
	Attack rate residents	Attack rate staff *	Duration[v] (days)	COVID-19 deaths	Hospital admissions	Residents isolating	Staff cohorted	Staff tested[φ]	Closed to visitors	Enhanced cleaning	PPE[ψ] available	Uptake[µ] residents	Uptake[µ] staff
A	16/30 (53%)	16/60 (27%)	63	2	5	All	Yes	Yes	Yes[†]	Yes	Yes	25/30 (83%)	147/183 (80%)[a]
B	6/15 (40%)	4/22 (18%)	50	1	3	Cases	No	Yes	Yes	Yes	Yes	15/15 (100%)	12/22 (55%)
C	1/12 (8%)	1/35 (3%)	30	0	0	Cases	Yes	Yes	Yes	Yes	Yes	12/12 (100%)	24/25 (96%)

*Approximate staff attack rates, based on numbers of non-agency staff; [v]Period between onset/ swab dates of index case, and 28 days after illness onset for the final case; [†]With the exception of end of life visits; [φ]as per PHE guidelines: daily Lateral Flow Tests (LFT) for at least 5 days followed by twice weekly LFT and once weekly PCR testing; [ψ]Personal Protective Equipment; [µ]Receipt of 1 or more dose >=14 days prior to onset in the index case; [a]Staff vaccination figures provided for whole facility, not just the short stay unit. No dates reported so figures may not accurately represent vaccine-induced immunity
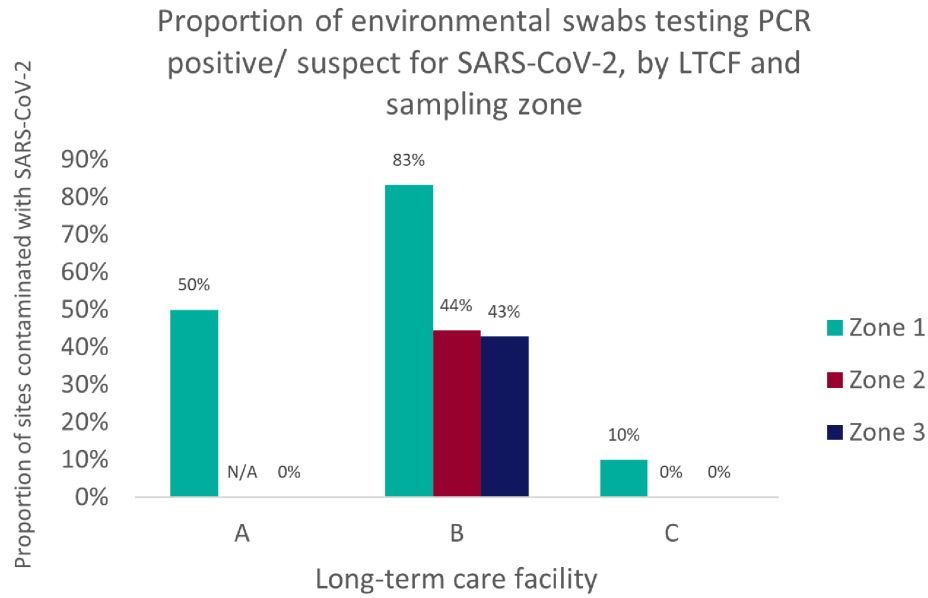
Figure 3. Proportion of sampling sites testing PCR positive for SARS-CoV-2, by sampling zone. Zone 1 represents areas/ equipment used by COVID-19 positive residents; Zone 2: areas/facilities used by both residents and staff; Zone 3: staff-only areas/equipment. There were no zone 2 areas to sample in LTCF A, since all residents were confined to their rooms.
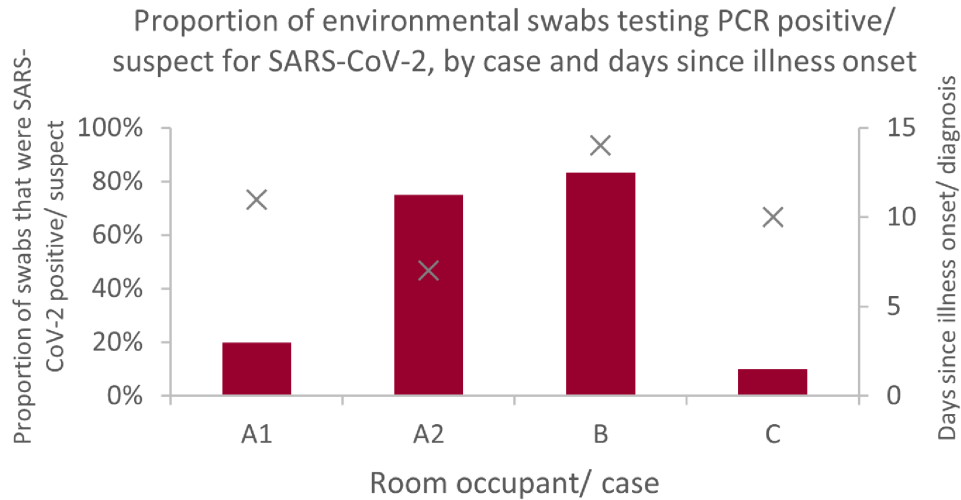

Figure 4. Proportion of sample sites that tested positive for SARS-CoV-2 RNA within the rooms of infected residents. Resident A1 had fever and slight cough and was bed/chair-bound; A2 had a cough and was mobile with a wheelchair; B reported only lethargy, and was independently mobile; C was asymptomatic and independently mobile; this individual's positive PCR result was unexpected given history of prior infection and vaccination.

(0%) from facility C, meaning there was insufficient data to assess clinical and epidemiological risk factors for infection. None of the respondents raised concerns about access to PPE as recommended in national guidelines for working in care homes.

Discussion

The greatest proportions of SARS-CoV-2 positive/ suspect sample sites were found in the immediate vicinity of laboratory-confirmed COVID-19 cases, which is consistent with findings from other studies and indicates that environmental swabbing

Table 4. Proportion of common touch point and elevated sampling sites testing positive for SARS-CoV-2 RNA, by LTCF.

LTCF	No. (proportion) common touch sites positive for SARS-CoV-2	No. (proportion) elevated sites positive for SARS-CoV-2
A	5/17 (29%)	2/10 (20%)
B	10/20 (50%)	6/7 (86%)
C	0/19 (0%)	1/10 (10%)
Total	**15/56 (27%)**	**10/28 (36%)**

can detect the presence of an infected individual. (Onakpoya *et al.*, 2021) The proportion of SARS-CoV-2 positive/ suspect sites varied considerably within zone 1 however, even between rooms with similar layouts and cleaning regimes occupied by individuals with comparable symptom profiles. The exact timing of cleaning was not captured and may have affected these results, though variation was also observed in elevated sites which were unlikely to have been cleaned as part of daily routine. Equally, the sensitivity of surface swabbing may have differed between rooms though the same sampler swabbed both. Environmental sampling around COVID-19 patients evacuated from the Diamond Princess cruise ship demonstrated a similar lack of correlation between clinical signs of illness and levels of environmental contamination. (Santarpia *et al.*, 2020) It is likely that our findings illustrate the myriad of environmental, clinical, behavioural and pathogen factors affecting dispersion of the virus, (Moore *et al.*, 2021) which must be controlled for in any analysis of infection risk by indirect transmission.

Survey response rates were poor, which is likely to reflect the pressures staff were under at the time. Consequently, there was insufficient epidemiological information to assess whether transmission occurred via fomites or long-distance aerosol during these outbreaks. Concentrations of SARS-CoV-2 RNA were very low for all positive and suspect samples, therefore it is highly unlikely that viable virus was present. (Huang *et al.*, 2020; Transmission of Covid-19 in the Wider Environment Group (TWEG) reporting to UK Scientific Advisory Group on Emergencies (SAGE) 2020) This is in keeping with results from environmental surveillance in Canadian care homes. (Nelson *et al.*, 2021)

The fact that fingertip swabs were all PCR negative for SARS-CoV-2, despite observing infected residents touch various items which returned a positive result, was surprising: people typically touch their nose, eyes and mouth more than 20 times per hour and an experimental study suggests that the virus can persist on skin for at least 8 hours at body temperature. (Harbourt *et al.*, 2020; Kwok *et al.*, 2015) Sampling may have occurred too late to detect viral shedding, since participants were between seven and 14 days of diagnosis, and the concentration of virus on fomites was low which might reduce

the likelihood of transfer to fingers. It is also possible that residents applied hand sanitiser unobserved, or that the sampler did not apply sufficient pressure or friction to pick up viral RNA. (Mbithi *et al.*, 1992)

Notably, facility A experienced the highest attack rates despite implementing more comprehensive IPC and cleaning measures compared to facilities B and C. Residents in facility A were more susceptible to infection than those in facilities B and C, having only received the first dose of vaccine shortly before the outbreak onset. (Shrotri *et al.*, 2021; Tenforde *et al.*, 2021) Facility A also had a higher rate of admissions from the local hospitals and these factors, as well as the relatively large size of the facility, may have increased the probability of multiple introductions of the virus to the premises. (Burton *et al.*, 2020; Shallcross *et al.*, 2021) Unfortunately staff survey response rates were too low to enable a comparative analysis of other infection risk factors within and outside the facility.

High attack rates may also have reflected community case rates, which peaked at the end of December and remained high through January (see Figure 2 for pilot LTCF outbreak trajectories). This surge in case rates was fuelled by emergence of the more transmissible B.1.1.7 Alpha variant, which quickly entered English LTCFs. (Krutikov *et al.*, 2021) At this time a substitution at the E484K location of the receptor binding domain also emerged, raising concerns that the virus might evade the host immune response. (Wise, 2021) Six clinical samples were sequenced and were all of the B.1.1.7 Alpha variant with no E484K substitution, however we cannot exclude the possibility that multiple strains of the virus were contributing to these outbreaks.

Results from surface swabbing provided some reassurance that facility A (with staff cohorting and enhanced IPC measures) was effectively containing the environmental spread of the virus, in contrast to LTCF B (without cohorting) in which viral RNA was widely distributed. Repeat sampling 14 days after the initial visit to facility B yielded a much lower proportion of SARS-CoV-2 positive/suspect sites. Since the first visit corresponded with the end of the final case's infectious period and no further cases of COVID-19 were identified it is reasonable to assume that nobody in the facility was actively shedding virus at the second sampling visit. Our observations could reflect the effectiveness of cleaning protocols introduced between sampling visits or of swabbing at the first round of sampling, or degradation of viral RNA over a 14 day period. (Onakpoya *et al.*, 2021; van Doremalen *et al.*, 2020) Facility C was the only one to isolate its resident case on a separate floor/wing which may have helped reduce egress to other areas within the home. However, this individual's history of vaccination and prior infection, and a negative repeat PCR test suggest that the diagnosis was a false positive and they were not shedding SARS-CoV-2 at the time of sampling.

Elevated sampling sites, being cleaned less regularly, may be a more pragmatic means of SARS-CoV-2 detection than common touch points: of the four sites that remained positive/suspect

for SARS-CoV-2 on a repeat visit to facility B, three were elevated. Reactive sampling, as applied in this pilot, will not distinguish between historic and current viral shedding but there is evidence that levels of surface contamination with SARS-CoV-2 RNA mirror contemporaneous levels of airborne SARS-CoV-2 RNA. (Cherrie *et al.*, 2021; Dumont-Leblond *et al.*, 2021) Air vents may be useful sentinel sampling points since three of four air vents in facility B tested positive for SARS-CoV-2 RNA, and in facility C the air vent was the only sampling site that tested suspect positive. Similar observations are reported from sampling ventilation grates in the Diamond Princess COVID-19 quarantine rooms, and respiratory viruses have been isolated from air filters in aeroplanes and large public buildings. (Goyal *et al.*, 2011; Korves *et al.*, 2011; Santarpia *et al.*, 2020) It is interesting that none of the air vents sampled from facility A tested positive for SARS-CoV-2 RNA, including one in a room that was otherwise quite heavily contaminated. This could have been an artefact of different sampling techniques, or reflect the design of the air vents, which were circular with a single ring opening rather than a slatted grate, though the vent that tested suspect positive in facility C was of the same circular design. Facility A may also have been better ventilated than the other facilities, however this seems unlikely given positive results in other elevated sites in the building.

The uncluttered environment in facility A, in reducing build-up of dust, may also have helped limit environmental spread of SARS-CoV-2. Evidence that respiratory droplets containing SARS-CoV-2 are adsorbed to dust and particulate matter, creating 'aerosolised fomites', is emerging (Andree, 2020; Conticini *et al.*, 2020; Qu *et al.*, 2020; Renninger *et al.*, 2021; Setti *et al.*, 2020; Travaglio *et al.*, 2021) and in healthcare settings we have observed that elevated surfaces accumulate greater quantities of SARS-CoV-2 RNA in dusty environments such as changing rooms, bathrooms, and cluttered spaces (unpublished data). This merits further investigation.

Limitations

This pilot has several limitations, not least the small sample size, lack of control sites and heterogeneity of LTCFs. Our interpretation of results is speculative and intended to generate hypotheses rather than answer questions.

Between-site variation in layout and infrastructure means that sampling frames cannot be entirely standardised, and there may be a tendency to oversample areas that are visibly soiled. Sampling technique may also vary between samplers. Results from surface swabs represent a snapshot in time and cover a fraction of the LTCF environment so we may not have accurately captured overall levels of environmental contamination. Among other things these may have been influenced by trends in community prevalence of COVID-19 (affecting risk of importation), expansion of new variants, and the effects of vaccination rollout (affecting viral shedding and transmissibility).

We were unable to confirm whether the diagnostic test for the single resident case in facility C was a true positive, therefore the SARS-CoV-2 RNA detected in this individual's rooms may have been residual from previous occupants or their carers. This bias also applies to the other facilities to some extent, since all were likely to have been exposed to the virus (whether or not it manifested clinically) at some point prior to the outbreak.

Sequencing data were only available for minority of outbreak samples therefore we were unable to assess whether new or multiple strains were responsible for the outbreaks in question.

Conclusions and recommendations

We have successfully recruited three pilot LTCF to the DISin-FECT study and observed SARS-CoV-2 RNA on a high proportion of surfaces around individuals with a laboratory-confirmed infection, though this varied considerably within and between settings.

This pilot demonstrates that surface swabbing can provide reassurance that IPC measures such as self-isolation, staff cohorting and enhanced cleaning collectively reduce egress of the virus from quarantine rooms to the wider care home environment. The heterogeneity of settings and situations means that we cannot assess impact of environmental contamination or individual IPC measures on transmission risk, however. An analysis of national LTCF-level data would be beneficial to assess which, if any, IPC measures influence attack rates during outbreaks of SARS-CoV-2.

Results also highlight that LTCF staff can be overburdened with information requests during outbreaks. There is a need for efficient and parsimonious data collection tools, using routine sources of intelligence wherever possible, to gather sufficient epidemiological information for the interpretation of environmental surveillance data.

Finally, sampling frameworks focussing on elevated surfaces/those which accumulate particulate matter may be less susceptible to the effects of cleaning regimes and thus a useful tool for detecting outbreaks and evaluating IPC measures.

In summary: this pilot demonstrates the potential utility of surface swabbing in LTCF to assess environmental spread and effectiveness of IPC measures, and monitor for outbreaks of infectious disease. At present, the potential to assess SARS-CoV-2 infection risk via indirect routes is limited by the heterogeneity of LTCFs and their populations, and challenges around data collection.

Data availability
Underlying data
To preserve anonymity of LTCF residents and staff, the study data are stored on a secure drive hosted by Public Health

England (PHE) Field Services South West. Access to personal identifiable data is restricted to personnel responsible for outbreak investigations. Non-identifiable data may be made available to others upon formal request (please contact the corresponding author for an information request form) and subject to approval from the PHE Office for Data Release.

Extended data
Open Science Framework: COVID-19: Detecting Indirect Spread in Facilities for Enhanced Care sTudy (COVID-19: DISinFECT). Investigating environmental epidemiology of SARS-CoV-2 in long term care facilities in England. Protocol v4.1. https://doi.org/10.17605/OSF.IO/3QN9Z (Kwiatkowska & Ready, 2021)

This project contains the following files:

- DISinFECT_Protocol_OSF.pdf. The protocol for this research study.

- DISinFECT_staffsurvey.pdf. The electronic survey distributed to staff to collect information on

epidemiological and clinical risk factors for SARS-CoV-2 infection.

- DISinFECT_Tools_line list_v6.xlsx. The data collection template for LTCF residents: clinical and epidemiological risk factors for SARS-CoV-2 infection.

- DISinFECT_Tools_setting log_v2.xlsx. The data collection template for details of LTCF layout and staffing arrangements.

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

Acknowledgements
The authors would like to express thanks to the staff and residents of care homes who supported these investigations during a very challenging time. Also to acknowledge the hard work of regional Health Protection Teams and local authorities throughout the SARS-CoV-2 epidemic, along with laboratory staff without whom this work would not have been possible.

References

Andree BPJ: **Incidence of COVID-19 and Connections with Air Pollution Exposure : Evidence from the Netherlands.** Policy Research Working Paper; No. 9221. World Bank, Washington, DC. Washington, DC. 2020.
Reference Source

Ben-Shmuel A, Brosh-Nissimov T, Glinert I, *et al.*: **Detection and Infectivity Potential of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Environmental Contamination in Isolation Units and Quarantine Facilities.** *Clin Microbiol Infect.* 2020; **26**(12): 1658–62.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Burton JK, Bayne G, Evans C, *et al.*: **Evolution and Effects of COVID-19 Outbreaks in Care Homes: A Population Analysis in 189 Care Homes in One Geographical Region of the UK.** *Lancet Healthy Longev.* 2020; **1**(1): e21–31.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Cherrie JW, Cherrie MPC, Smith A, *et al.*: **Contamination of Air and Surfaces in Workplaces with SARS-CoV-2 Virus: A Systematic Review.** *Ann Work Expo Health.* 2021; wxab026.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Conticini E, Frediani B, Caro D: **Can Atmospheric Pollution Be Considered a Co-Factor in Extremely High Level of SARS-CoV-2 Lethality in Northern Italy?** *Environ Pollut.* 2020; **261**: 114465.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Dumont-Leblond N, Veillette M, Bhérer L, *et al.*: **Positive No-Touch Surfaces and Undetectable SARS-CoV-2 Aerosols in Long-Term Care Facilities: An Attempt to Understand the Contributing Factors and the Importance of Timing in Air Sampling Campaigns.** *Am J Infect Control.* 2021; **49**(6): 701–6.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Goyal SM, Anantharaman S, Ramakrishnan MA, *et al.*: **Detection of Viruses in Used Ventilation Filters from Two Large Public Buildings.** *Am J Infect Control.* 2011; **39**(7): e30–8.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Greenhalgh T, Jimenez JL, Prather KA, *et al.*: **Ten Scientific Reasons in Support of Airborne Transmission of SARS-CoV-2.** *Lancet.* 2021; **397**(10285): 1603–5.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Harbourt DE, Haddow AD, Piper AE, *et al.*: **Modeling the Stability of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) on Skin, Currency, and Clothing.** *PLoS Negl Trop Dis.* 2020; **14**(11): e0008831.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Huang CG, Lee KM, Hsiao MJ, *et al.*: **Culture-Based Virus Isolation to Evaluate Potential Infectivity of Clinical Specimens Tested for COVID-19.** *J Clin Microbiol.* 2020; **58**(8): e01068–20.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Inns T, Harris J, Vivancos R, *et al.*: **Community-Based Surveillance of**

Norovirus Disease: A Systematic Review. *BMC Infect Dis.* 2017; **17**(1): 657.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Inns T, Keenan A, Huyton R, *et al.*: **How Timely Closure Can Reduce Outbreak Duration: Gastroenteritis in Care Homes in North West England, 2012–2016.** *BMC Public Health.* 2018; **18**(1): 488.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Inns T, Clough HE, Harris JP, *et al.*: **Estimating the Burden of Care Home Gastroenteritis Outbreaks in England, 2014–2016.** *BMC Infect Dis.* 2019; **19**(1): 12.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Korves TM, Johnson D, Jones BW, *et al.*: **Detection of Respiratory Viruses on Air Filters from Aircraft.** *Lett Appl Microbiol.* 2011; **53**(3): 306–12.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Krutikov M, Hayward A, Shallcross L: **Spread of a Variant SARS-CoV-2 in Long-Term Care Facilities in England.** *N Engl J Med.* 2021; **384**(17): 1671–73.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Kwiatkowska R, Ready D: **COVID-19: Detecting Indirect Spread in Facilities for Enhanced Care sTudy (COVID-19: DISinFECT). Investigating environmental epidemiology of SARS-CoV-2 in long term care facilities in England.** Protocol v4.1. 2021.
http://www.doi.org/10.17605/OSF.IO/3QN9Z

Kwok YL, Gralton J, McLaws ML: **Face Touching: A Frequent Habit That Has Implications for Hand Hygiene.** *Am J Infect Control.* 2015; **43**(2): 112–14.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Mbithi JN, Springthorpe VS, Boulet JR, *et al.*: **Survival of Hepatitis A Virus on Human Hands and Its Transfer on Contact with Animate and Inanimate Surfaces.** *J Clin Microbiol.* 1992; **30**(4): 757–63.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Moore G, Rickard H, Stevenson D, *et al.*: **Detection of SARS-CoV-2 within the Healthcare Environment: A Multi-Centre Study Conducted during the First Wave of the COVID-19 Outbreak in England.** *J Hosp Infect.* 2021; **108**: 189–96.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Morciano M, Stokes J, Kontopantelis E, *et al.*: **Excess Mortality for Care Home Residents during the First 23 Weeks of the COVID-19 Pandemic in England: A National Cohort Study.** *BMC Med.* 2021; **19**(1): 71.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Nelson A, Kassimatis J, Estoque J, *et al.*: **Environmental Detection of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from Medical Equipment in Long-Term Care Facilities Undergoing COVID-19 Outbreaks.** *Am J Infect Control.* 2021; **49**(2): 265–68.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Onakpoya IJ, Heneghan CJ, Spencer EA, *et al.*: **SARS-CoV-2 and the Role of**

Fomite Transmission: A Systematic Review [version 3; peer review: 2 approved]. *F1000Res.* 2021; **10**: 233.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Ong SWX, Tan YK, Chia PY, *et al.*: **Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) from a Symptomatic Patient.** *JAMA.* 2020; **323**(16): 1610–1612.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Qu G, Li X, Hu L, *et al.*: **An Imperative Need for Research on the Role of Environmental Factors in Transmission of Novel Coronavirus (COVID-19).** *Environ Sci Technol.* 2020; **54**(7): 3730–32.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Renninger N, Nastasi N, Bope A, *et al.*: **Indoor Dust as a Matrix for Surveillance of COVID-19.** ed. Angela D. Kent. *mSystems.* 2021; **6**(2): e01350–20.
PubMed Abstract | **Publisher Full Text**

Santarpia JL, Rivera DN, Herrera VL, *et al.*: **Aerosol and Surface Contamination of SARS-CoV-2 Observed in Quarantine and Isolation Care.** *Sci Rep.* 2020; **10**(1): 12732.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Setti L, Passarini F, De Gennaro G, *et al.*: **SARS-Cov-2RNA Found on Particulate Matter of Bergamo in Northern Italy: First Evidence.** *Environ Res.* 2020; **188**: 109754.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Shallcross L, Burke D, Abbott O, *et al.*: **Factors Associated with SARS-CoV-2 Infection and Outbreaks in Long-Term Care Facilities in England: A National Cross-Sectional Survey.** *Lancet Healthy Longev.* 2021; **2**(3): E129–42.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Shrotri M, Krutikov M, Palmer T, *et al.*: **Vaccine Effectiveness of the First Dose of ChAdOx1 NCoV-19 and BNT162b2 against SARS-CoV-2 Infection in Residents of Long-Term Care Facilities in England (VIVALDI): A Prospective Cohort Study.** *Lancet Infect Dis.* 2021; S1473-3099(21)00289-9.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Strausbaugh LJ, Sukumar SR, Joseph CL: **Infectious Disease Outbreaks in Nursing Homes: An Unappreciated Hazard for Frail Elderly Persons.** *Clin Infect Dis.* 2003; **36**(7): 870–76.
PubMed Abstract | **Publisher Full Text**

Tenforde MW, Olson SM, Self WH, *et al.*: **Effectiveness of Pfizer-BioNTech and Moderna Vaccines Against COVID-19 Among Hospitalized Adults Aged ≥65 Years - United States, January-March 2021.** *MMWR Morb Mortal Wkly Rep.* 2021; **70**(18): 674–679.
PubMed Abstract | **Publisher Full Text**

Transmission of Covid-19 in the Wider Environment Group (TWEG) reporting to UK Scientific Advisory Group on Emergencies (SAGE): **Monitoring the Presence and Infection Risk of SARS-CoV-2 in the Environment: Approaches, Limitations and Interpretation**. 2020.
Reference Source

Travaglio M, Yu Y, Popovic R, *et al.*: **Links between Air Pollution and COVID-19 in England.** *Environ Pollut.* 2021; **268**(Pt A): 115859.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Wise J: **Covid-19: The E484K Mutation and the Risks It Poses.** *BMJ.* 2021; **372**: n359.
PubMed Abstract | **Publisher Full Text**

Ye G, Lin H, Chen S, *et al.*: **Environmental Contamination of SARS-CoV-2 in Healthcare Premises.** *J Infect.* 2020; **81**(2): e1–5.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

van Doremalen N, Bushmaker T, Morris DH, *et al.*: **Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1.** *N Engl J Med.* 2020; **382**(16): 1564–67.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**