Journal Pre-proof

DO MOBILE PHONE SURFACES CARRY SARS-COV-2 VIRUS? A SYSTEMATIC REVIEW WARRANTING THE INCLUSION OF A "6th" MOMENT OF HAND HYGIENE IN HEALTHCARE

Matthew Olsen, Thibaut Demaneuf, Gobinddeep Singh, Adrian Goldsworthy, Peter Jones, Mark Morgan, Rania Nassar, Abiola Senok, Rose Ghemrawi, Reem Almheiri, Hussain Al Marzooqi, Sumaya Almansoori, Abdullah Albastaki, Rashid Almansoori, Simon McKirdy, Rashed Alghafri, Lotti Tajouri

PII: S1876-0341(23)00284-8

DOI: https://doi.org/10.1016/j.jiph.2023.08.017

Reference: JIPH2211

To appear in: *Journal of Infection and Public Health*

Received date: 27 June 2023

Revised date: 15 August 2023

Accepted date: 22 August 2023

Please cite this article as: Matthew Olsen, Thibaut Demaneuf, Gobinddeep Singh, Adrian Goldsworthy, Peter Jones, Mark Morgan, Rania Nassar, Abiola Senok, Rose Ghemrawi, Reem Almheiri, Hussain Al Marzooqi, Sumaya Almansoori, Abdullah Albastaki, Rashid Almansoori, Simon McKirdy, Rashed Alghafri and Lotti Tajouri, DO MOBILE PHONE SURFACES CARRY SARS-COV-2 VIRUS? A SYSTEMATIC REVIEW WARRANTING THE INCLUSION OF A "6th" MOMENT OF HAND HYGIENE IN HEALTHCARE, *Journal of Infection and Public Health,* (2023) doi:https://doi.org/10.1016/j.jiph.2023.08.017

DO MOBILE PHONE SURFACES CARRY SARS-COV-2 VIRUS? A SYSTEMATIC REVIEW WARRANTING THE INCLUSION OF A "6th" MOMENT OF HAND HYGIENE IN HEALTHCARE

Matthew Olsen[1], Thibaut Demaneuf [2], Gobinddeep Singh[1], Adrian Goldsworthy[1], Peter Jones[1], Mark Morgan[1], Rania Nassar [4, 5], Abiola Senok[4], Rose Ghemrawi[7], Reem Almheiri[8], Hussain Al Marzooqi[3,8], Sumaya Almansoori[8], Abdullah Albastaki[3,8], Rashid Almansoori[3,8], Simon McKirdy[6], Rashed Alghafri [,6,8] and Lotti Tajouri[1,3,6 *]

[1] Faculty of Health Sciences and Medicine, Bond University, Robina, QLD, Australia (AU)
[2] The Pacific Community (SPC), New Caledonia (NC)
[3] Dubai Police Scientists Council, Dubai Police, Dubai, United Arab Emirates (UAE)
[4] College of Medicine, Mohammed Bin Rashid University of Medicine and Health Sciences, Dubai, United Arab Emirates
[5] School of Dentistry, College of Biomedical and Life Sciences, Cardiff University, Cardiff, United Kingdom (UK)
[6] Harry Butler Institute, Murdoch University, Murdoch WA 6150, Australia (AU)
[7] College of Pharmacy, Al Ain University, Abu Dhabi P.O. Box 112612, United Arab Emirates
[8] General Department of Forensic Sciences and Criminology, Dubai Police, Dubai, United Arab Emirates (UAE)

[*] Correspondence:
Lotti Tajouri
Associate Professor- Genomics and Molecular Biology
Bond University | Gold Coast, Queensland, 4229, Australia
ltajouri@bond.edu.au
Tel: +61 755951148

Conflict and Interest: The authors have stated explicitly that there are no conflicts of interest in connection with this article.

Abstract

Background.

Mobile phones, used in billions throughout the world, are high-touch devices subject to a dynamic contamination of microorganisms and rarely considered as a dynamic fomite to sanitise systematically. The emergence of SARS-CoV-2 resulted in the COVID-19 pandemic, arguably the most impactful pandemic of the 21st century with millions of deaths and disruption of all facets of modern life globally.

Aim.

To perform a systematic review of the literature exploring SARS-CoV-2 presence as a contaminant on mobile phones.

Methods.

A systematic search (PubMed and Google Scholar) of literature was undertaken from December 2019 to February 2023 identifying English language studies. Studies included in this

review specifically identified or tested for the contamination of the SARS-CoV-2 virus or genome on mobile phones while studies SARS-CoV-2 testing for SARS-COV-2 in environments and/or other fomites samples than but not mobile phones were excluded.

Results.

A total of 15 studies with reports of SARS-CoV-2 contamination on mobile phones between 2020-2023 were included. Amongst all studies, which encompassed ten countries, 511 mobile phones were evaluated for the presence of SARS-CoV-2 contamination and 45% (231/511) were positive for SARS-CoV-2. All studies were conducted in the hospital setting and two studies performed additional testing in residential isolation rooms and a patient's house. Four studies (3 in 2020 and one in 2021) reported 0% contamination while two other studies (in 2020 and 2022) reported 100% of mobile phone contamination with SARS-COV-2. All other studies report mobile phones positive for the virus within a range of 4% to 77%.

Conclusion.

A total of 45% of mobile phones are contaminated with SARS-CoV-2 virus. These devices might be an important fomite vector for viral dissemination worldwide. Competent health authorities are advised/recommended to start a global implementation of mobile phone decontamination by introducing regulations and protocols in public health and health care settings such as the 6th moment of hand washing.

Keywords:

SARS-CoV-2, COVID-19, Coronavirus, mobile phones, cell phones, fomite, trojan horse, "third-hand", epidemic, pandemic, ultraviolet-C, mobile phone sanitisation.

Introduction

In December 2022, there were 7.26 billion mobile phones in use globally with different mobile phone market penetration per country [1]. Some studies have demonstrated that mobile phones are high touch surfaces used on average more than 3 hours a day [2]. Additionally, extensive literature and a recent scoping review have shown that mobile phones are highly and dynamically contaminated with microbes sourced from the environment and the hands of their owners [3]. Bacteria, fungi, parasites and viruses have been detected in high numbers as contaminants on mobile phones [4]. Taken together, the extensive use of mobile phones as contaminated platforms raises high concerns of frequent cross-contamination of pathogenic microorganisms to hands [5]. Mobile phones accommodating various microbes are constantly handled and manipulated close to anatomical entry mucosal cavity points such as mouth, nose, eyes with possible subsequent risks of self-inoculation of pathogens. Furthermore, urbanisation

of dense populations and modern transport favour a higher risk of microbial spread by means of these devices that are transported everywhere to all whereabout of their users. While hand washing is actively practiced, cross contamination from mobile phones to hands negate that basic life-saving hand hygiene habit and mobile phones therefore may act as real Trojan horse. Following the first case detected in China on December 2019, the rest of the world was introduced to the novel coronavirus SARS-CoV-2 that would go on to cause 6.9 million (as per May 2023) deaths and infect more than 765 million individuals [6]. The original "SARS-CoV-2" identified in early 2020 has since undergone various mutations with Alpha (B.1.1.7) variant and the Omicron variant contributing significantly to the global dissemination. On Friday 5th of May 2023, the Director General of the World Health Organization (WHO) Tedros Ghebreyesus, declared the end of COVID-19 as a global health emergency. Various non-pharmaceutical interventions including social distancing, enhanced hand hygiene and environmental decontamination, mandatory mask wearing, border closures and travel restrictions were put in place to limit the spread of SARS-CoV-2. When the virus adhesion virulence was studied, the spread and reproducing number were mainly reported to be through droplets and, later in time, through aerosols too. However, very little attention was placed on fomite-based transmission beside reports of the presence of the SARS-CoV2 on surfaces particularly that of mobile phones.

Despite the United States Centre for Disease Control and Prevention (CDC) statement that approximately 80% of infectious diseases are transmitted via contact with hands [7], there is currently very little emphasis on the role of mobile phones as fomites leading to high-risk healthcare and community spread of infections and propagation of microbes in the community. However, a recent systematic review in 2022 examined 50 studies from 23 countries and concluded that the use of mobile phones by healthcare workers without proper disinfection may imply a risk for nosocomial infection [8]. Reduced attention of the risk of microbial dissemination from mobile phones has resulted in a paucity of health policies or protocol implementations to effectively sanitise these important viable microbial contaminated platforms.

In April 2020, Olsen and colleagues published a scoping review highlighting the potential threat of mobile phones, bypassing hand hygiene and acting as "trojan horses" for the dissemination of microbes with great emphasis of SARS-CoV-2 propagation [3] raising awareness to government health authorities to develop protocols to sanitise mobile phones to limit the dissemination of microbes and SARS-CoV-2. Additionally, further research that

emerged in 2020 with Riddell et al. demonstrated that the virus could be recovered and remain infectious on non-porous and glass surfaces such as mobile phones for up to 28 days [9].

This review aims to consolidate all relevant literature pertaining to mobile phone contamination with the SARS-CoV-2 virus and to report the extent of viral contamination of such platforms. We hope to raise awareness to public health and biosecurity enforcement authorities that mobile phones are possibly important contributors to pandemics.

Methods

This systematic review follows the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). This systematic review study was not registered.

Data sources and search strategy

We searched PubMed and Google Scholar for English studies that identified the presence of the SARS-CoV-2 virus responsible for COVID-19 on mobile phones/smartphones in all settings including health care and the community. The PubMed database was chosen as a means for selecting relevant biomedical journals and publications, whilst google scholar was selected to identify grey literature and associated pre-print articles and manuscripts that would not appear on the PubMed search.

Given the nature of emerging research concerning SARS-CoV-2, additional citations were investigated manually and studies that did not appear in both the PubMed and Google Scholar search were included due to their relevance for this review. The final search for the review was performed on the 25th of May 2023.The following key words and terms were developed in MEDLINE for the PubMed database search and adjustments were made for the Google Scholar search. (“SARS-CoV-2” [MeSH] OR “COVID-19” [MeSH] OR “Coronavirus” [MeSH] OR “Coronavirus disease” OR “Coronavirus disease 2019” OR “Virus” [MeSH] OR “Viral Infections”[MeSH]) AND (“fomites” [MeSH] OR fomite* OR “Cross infection” [MeSH] OR “nosocomial” OR “nosocomial disease” OR “nosocomial diseases” OR “Microbial flora”[MeSH] OR microbiota* OR microbiology*) AND (“mobile phone” OR “mobile phones” OR “Cell Phones”[MeSH] OR “cellular phones” OR “cellular phone” OR “Personal Digital Assistant” OR “personal digital assistants” OR “Computers, Handheld”[MeSH] OR “smartphone” OR “smartphones”) AND (physician OR physicians OR doctor OR doctors OR

student OR students OR dentist OR dentists OR general practitioner OR aged-care worker OR health personnel OR medical personnel OR dental personnel OR university OR college OR university college OR teaching institution OR community OR public OR general public).

Study Selection

Studies were eligible for inclusion if the study design described tested swab samples taken from mobile phones with the aim to assess the presence of SARS-CoV-2 contamination, with positive or negative results of SARS-CoV-2 RNA irrespective of the confirmation of viral viability or infectious capacity.

Scientific literature-based studies were excluded if SARS-CoV-2 contamination was directed to assess different fomites but did not report or investigate mobile phones. Additionally, studies that identified all other microbial populations on tested mobile phones but did not aim at investigating SARS-CoV-2 detection were excluded.

Finally, studies that identified methods of sanitising mobile phones to mitigate the potential contamination and spread of the SARS-CoV-2 virus were excluded.

Following the systematic search from PubMed and Google Scholar, we uploaded the selected studies titles and abstracts to RefWorks and removed any duplicates. One author (MO) independently screened articles for eligibility, first screening title and abstracts. The full text reviews of the remaining articles were undertaking by two authors (MO and TD) to determine the final eligibility for systematic review. Disagreements were resolved with discussion with the author (LT) to reach consensus.

Data extraction and quality assessment

One author (MO) extracted and compiled the data into a Microsoft Excel spreadsheet. Extracted data related to study information (author/year, country), study design (target organism (strain/variant), swab type, swab transport protocol, identification technique, RNA extraction kit/ RTq-PCR protocol, target gene identification for PCR, SARS-CoV-2 cell culture experimentation (yes/no), cell culture protocol, characteristics of the study (population, setting, number of mobile phone samples, specificity of SARS-CoV-2 profiling techniques (low, medium, high, very high), threshold for cell culture experimentation, information of the outcomes (number of positive samples (n), percentage (%) of positive phones, finally the study limitations).

The data was independently put through quality assurance and quality checks by three authors (MO, TD and LT). Neither researcher was blinded to the journal and authors.

Analyses

We performed a qualitative analysis of the study characteristics and compiled the quantitative data for all studies included in this systematic review to achieve a synthesis of SARS-CoV-2 contamination from mobile phones since the onset of the COVID-19 pandemic. This study did not use a strict meta-analysis technique since we did not report the percentage of contaminated mobile phones with 95% confidence intervals and nor did we calculate weighted means. The reasons are associated with the fact that viral and other microbial contamination on the surface of mobile phones depend on numerous factors from epidemiological circumstances, time and location of swabs, shedding of such microorganisms present on humans, etc... Nonetheless, the analysis performed outlines a comprehensive overview of mobile phone contamination with SARS-CoV-2.

Results

Study Selection

A total of 8297 articles were identified from the literature, with 53 articles from PubMed, 8240 articles from Google Scholar and an additional 4 articles identified through a grey-literature manual search. After duplicates were removed, 8297 articles remained and were further screened based on the inclusion criteria. Of these, 557 full-text articles were assessed for eligibility, of which 542 articles were excluded for not meeting the inclusion criteria. Following a series of exclusions, fifteen (15) articles met the criteria for full review and were included in the final analysis. **Figure 1** represents the PRISMA flow diagram outlining the selected studies that passed the criteria for full review.

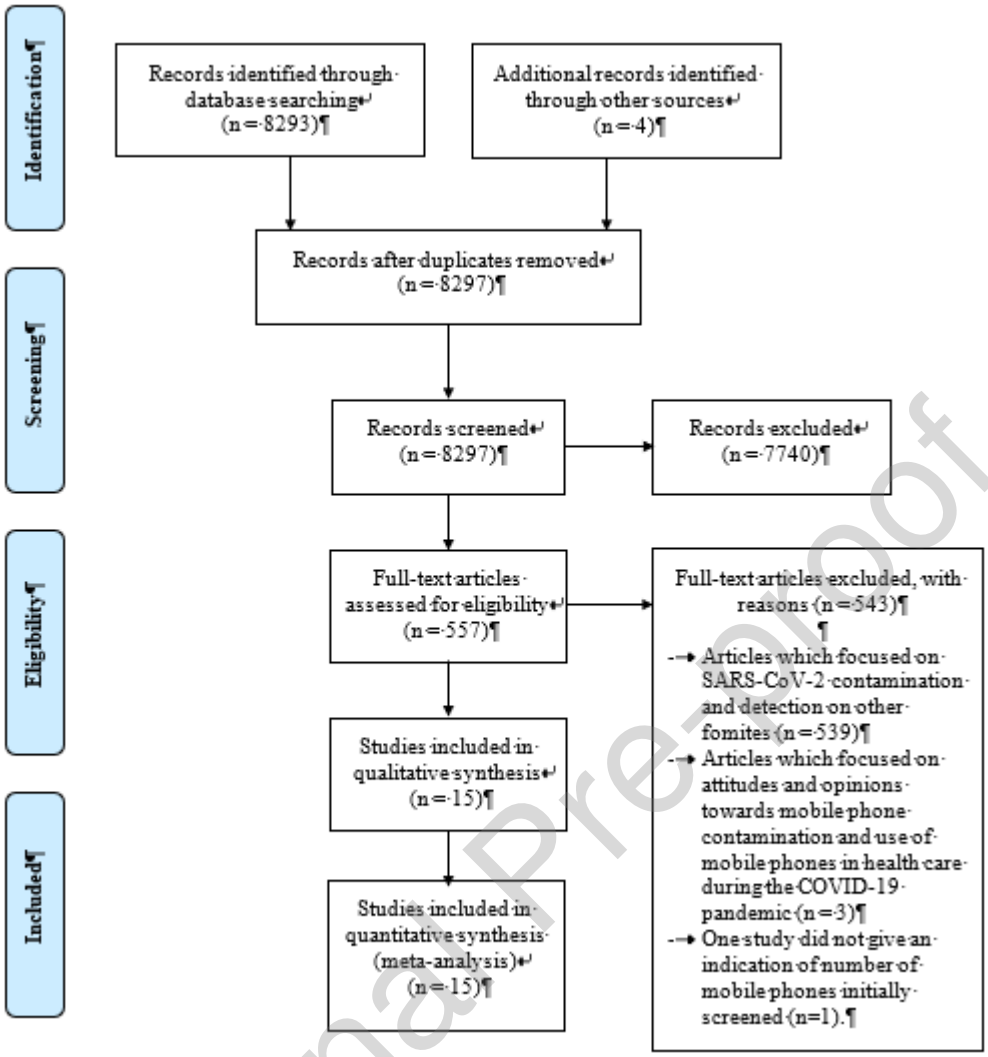


Figure 1. *PRISMA flow diagram of studies selected for full review.*

Table 1: *Study methodology; SARS-CoV-2 collection and identification protocols.*

Reference	Swab type	Swab transport protocol	Identification technique	RNA extraction kit / PCR protocol	PCR gene target	Median cycle threshold (Ct) of positive SARS-CoV-2 RT-PCR	Specificity of SARS-CoV-2 profiling techniques
[10] (Ma et al., 2020)	Wet cotton swabs.	Swabs were placed in 3 mL virus collection liquid	RNA extraction and quantitative reverse-transcription	Samples were analysed using RT-PCR (Roche 96 fluorescence qPCR instrument, Roche Molecular	Amplification of ORF1ab and N genes.	Ct (average) = 38.615	Medium

		(Yocon Biology, Inc).	polymerase chain reaction (RT-PCR).	Systems, Inc, Pleasanton, CA).			
[11] (Li et al., 2020)	Saline-moistened swabs.	NA	RNA extraction and qualitative RT-PCR.	NA	NA	NA	Low
[12] (Santarpia et al., 2020)	3 × 3 sterile gauze pads pre-wetted with 3 mL of phosphate buffered saline (PBS).	Samples were packed in 50 mL conical tubes.	RNA extraction and quantitative RT-PCR.	RNA extractions were performed using a Qiagen DSP Virus Spin Kit (QIAGEN GMbH, Hilden, Germany) and RT-PCR was performed using Invitrogen Superscript III Platinum One-Step Quantitative RT-PCR System.	Amplification of E gene.	NA	Medium
[13] (Kim et al., 2020)	Wet cotton swabs.	Swabs were submerged in 2 mL viral transport medium. Each sample was then individually wrapped and transported to the laboratory of CNU Hospital within 3 hours of sampling by a contracted car racer.	RNA extraction and real time RT-PCR (rRT-PCR).	RNA extractions were performed using an automated nucleic acid extraction system (AdvanSureTM E3 System; LG Chem, Seoul, Korea). The extracted RNA was amplified using a commercial rRT-PCR kit (PowerChekTM 2019-nCoV Real-time PCR Kit; KogeneBiotech, Seoul, Korea). Detection system (CFX96TM Real-time PCR detection system; Bio-Rad, Hercules, CA, USA) to detect the envelope (E) and RNA-dependent RNA polymerase (RdRP) genes.	Amplification of E and RdRP genes.	Ct (average) = 36.42	Medium
[14] (Wei et al., 2020)	Premoistened swabs (Copan).	NA	Unknown RNA extraction technique and RT-PCR.	NA	Amplification of ORF1ab and N genes.	NA	Low

[15] (Lei et al., 2020)	15-cm sterile flocked plastic swabs (Shenzhen Mairuikelin Company) moistened with viral transport medium (VTM).	Swabs placed in 15-mL tubes containing 3mL VTM.	RNA extraction and quantitative RT-PCR.	QIAGEN Viral RNA mini kit (QIAGEN).	Amplification of the ORF-1 or N genes.	Ct (average) = 44.4	High
[16] (Kyeong Seob Shin et al., 2020)	Sterile swabs moistened with distilled water.	Swabs were placed in viral transport medium.	RNA extraction and RT-PCR.	SARS-CoV-2 test kit (Allplex 2019-nCoV Assay, Seegene, Seoul, Korea).	Amplification of RdRp, N and E genes.	NA	Low
[17] (Chi-Chung Cheng et al., 2020)	Sterile cotton swab.	Swabs were then submerged in 2 mL VTM	RNA extraction and RT-PCR.	Each swab sample in VTM was vortexed and centrifuged at 13,000 × *g* for 1 minute, and 1 mL of the supernatant was used for nucleic acid extraction. PCR was carried out with the QuantiNova Probe RT-PCR kit (Qiagen).	Amplification of RdRp gene	NA	Medium
[18] (Ben-Shmuel et al., 2020)	6-inch cotton-tipped applicators.	Two wet swabs plus one dry swab was used and pooled into one 15-mL tube containing 2 mL transfer medium.	RNA extraction and RT-PCR.	Samples were vigorously vortexed, and from each elution 200 µL swab extraction were processed using the RNAdvance Viral kit (Beckman Coulter) on the Biomek i7 Automated Workstation (Beckman Coulter). PCR was performed using SensiFAST Probe Lo-ROX One-Step kit (Bioline).	Amplification of E gene	Ct (average) = 33.9	High
[19] (Espinoza et al., 2021)	Nylon FLOQ SwabTM.	Swabs placed in universal transport medium (UTMTM Copan Italia SPA, Italy) and stored at -80ºC.	RNA extraction and RT-PCR.	QIAmp viral RNA mini kit (QIAGEN, Hilden, Germany) and RealStar® SARS-CoV-2 Kit 1.0 (Altona-Diagnostics, Hamburg, Germany)	Amplification of the genes S and E of the virus.	Ct (average) = 35	High

[20] (Elbadawy et al., 2021)	Unspecified swabs.	NA	RNA extraction and quantitative RT-PCR.	Swabs were processed for RNA extraction with the Viral Nucleic Acid Extraction Kit II (Geneaid Biotechnology. PCR was carried out with the quantitative PCR (qPCR) Probe Assay.	NA	NA	Low
[21] (Young et al., 2021)	Dacron swabs were briefly dipped in Weise medium (Merck, 1.09468.0100) and then used to swab the bottom half of mobile phone screens.	Swabs were then introduced in sterile conical tubes containing Weise medium and briefly hand spun. Samples were processed for RT-PCR within 8 hr.	RTq-PCR (without RNA extraction).	RT-PCR was performed using Promega GoTaq Probe 1-Step RT-qPCR system (A6121) according to the manufacturer instructions and supplemented with SARS-CoV-2 N2 probes and primers (IDT#10006606) on an Illumina Eco Real-Time PCR System.	Amplification of N2 gene.	Ct (average) = 35.7	High
[22] (Bouchera bine et al., 2022)	Swabs were pre-moistened with sterile normal saline.	Swabs were placed in Zymos DNA/ RNA Shield Collection Tubes (Zymos Research, Irvine CA, USA).	RNA extraction and RT-PCR.	Qiagen QIAamp Viral Mini kit.	Amplification of the ORF-1 and/or N genes.	NA	Medium
[23] (Nagle et al., 2022)	Swabs were soaked in Viral Transport Medium.	Swabs were immersed in VTM tubes and divided equally into two sterile tubes, one for RTq-PCR and one stored at -80ºC for vitro viral isolation.	RNA extraction and quantitative RT-PCR.	m2000 Abbott Real Time Kit (Abbott, Chicago, IL, USA) or SARS-COV-2 Real Star Altona Kit (Altona Diagnostics France, Joue´-les-Tours, France).	Amplification of N and RdRp genes or S and E genes.	Ct (average) = 24	High

[24] (Leal et al., 2023)	2 × 2 cm sterile cotton gauze which was added into 3 to 7 mL of DMEM+.	All the freshly collected samples were placed on ice packs within 1-to-4 hours and subsequently refrigerated at 4 °C for up to 48 hours in a secure location before being transported at 0–4 °C to Edmonton, AB.	RNA extraction and real-time RT-PCR.	Viral RNA from the different specimen types was extracted on one of three platforms: easyMAG® (BioMerieux, Saint-Laurent, Quebec, Canada) with associated reagents; the MagMAX Express 96 or KingFisher Flex automated extraction and purification systems (Thermo Fisher Scientific, Waltham, Massachusetts, USA) with either the MagMAX-96 Viral RNA Isolation Kit (ABI) or the Maxwell HT Viral TNA custom kit (Promega); or the Hamilton STARlet automated extractor (Hamilton, Reno, Nevada, USA) with the Maxwell HT Viral TNA custom Kit. For E gene RT-qPCR TaqMan® Fast Virus One-Step RT-PCR Master Mix (ABI) was used. For N gene RT-qPCR, viral RNAs were extracted using QIAamp viral RNA min kit (Qiagen).	Amplification of the E and N genes.	NA	Medium

NA- Not available

Table 2: *Study characteristics of 15 articles investigating SARS-CoV-2 contamination on Mobile Phones.*

Reference	Country	Population	Number of Mobile Phone samples	Number of positive Mobile Phone samples for SARS-CoV-2	Percentage of positive samples (%)
[10] (Ma et al., 2020)	China	NHCP (Patient)	27	2	7.40%
[11] (Li et al., 2020)	China	NHCP (Patient)	3	0	0
[12] (Santarpia et al., 2020)	United States of America	NHCP (Patient)	18	14	77.8%
[13] (Kim et al., 2020)	Korea	NHCP (Patient)	24	9	37.5%
[14] (Wei et al., 2020)	China	NHCP (Patient)	5	0	0
[15] (Lei et al., 2020)	China	NHCP (Patient)	2	2	100%
[16] (Kyeong Seob Shin et al., 2020)	Korea	NHCP (Patient)	2	0	0
[17] (Chi-Chung Cheng et al., 2020)	Hong Kong	NHCP (Patient)	77	6	7.80%
[18] (Ben-Shmuel et al., 2020)	Israel	HCP, NHCP (Patient)	11	2	18.18%
[19] (Espinoza et al., 2021)	Brazil	HCP (Nurse and Nurse Assistant)	51	2	3.90%
[20] (Elbadawy et al., 2021)	Saudi Arabia	NHCP (Patient)	10	0	0
[21] (Young et al., 2021)	Chile	NHCP (Patient)	253	171	67.5%
[22] (Boucherabine et al., 2022)	United Arab Emirates (Dubai)	HCP	5	1	20%
[23] (Nagle et al., 2022)	France	NHCP (Patient)	19	19	100%

[24] (Leal et al., 2023)	Canada	NHCP (Patient)	4	1	25%
			511	**229**	**45%**

Note: HCP, Health-Care Professional; NHCP, Non-Health-Care Professional; ICU, Intensive Care Unit; ER, Emergency Room. All studies were undertaken in medical hospitals while Reference 11 was in a medical hospital & Residential Isolation Rooms and reference 19 was in a medical hospital (COVID isolation ward) & Community setting (Patient's house).

Table 3: Cell culture and CT value thresholds

Study ID	Cell culture	(Ct) medium cycle threshold to perform viral isolation test	Cell culture methodology	Presence of intact viruses
[12] (Santarpia et al., 2020)	Yes	NA	Vero E6 cells	No
[18] (Ben-Shmuel et al., 2020)	Yes	10 pfu/mL limit detection for CPE assay. Comparable to: **(Ct) = 34**	VERO E6 cells (ATCC-CRL-1586)	No
[19] (Espinoza et al., 2021)	Yes	NA	Vero cells (ATCC® CCL-81™)	No
[23] (Nagle et al., 2022)	Yes	**(Ct) <37**	Vero cells	No
[24] (Leal et al., 2023)	Yes	NA	Vero (ATCC #CCL-81) and Vero E6/TMPRSS2 (JCRB cell bank 1819)	**Cultivatable Virus (pfu/ml)** $1.95x10^2$

NA: Not available; References 1-11, 13-17, 20-22 did not mention any characteristics required for this table.

Study characteristics

Country

The systematic search identified 15 studies published between 2020 and 2023, representing 10 different countries including: China (n=5), South Korea (n=2), Brazil (n=1), United Arab Emirates (Dubai) (n=1), France (n=1), Chile (n=1), Israel (n=1), Saudi Arabia (n=1), the United States of America (n=1) and Canada (n=1)

Study participants

Table 2 provides a qualitative overview of the studies included in the review and identifies the proportion of positive SARS-CoV-2 mobile phones identified. The population consisted of non-Healthcare individuals (patient), Healthcare staff. Both healthcare workers and patients positive for SARS-CoV-2 had their mobile phones tested for contamination with the virus. 12 studies investigated non-Healthcare individuals (patients), two studies investigated Healthcare staff s and 1 study investigated both groups (**Table 2**).

Study settings

Studies were predominately conducted in Hospital "high risk" environments such as intensive care units (ICU), emergency rooms (ER), Infectious Disease wards and COVID isolation wards. [Hospital (n=8), Hospital and Residential Isolation Rooms (n=1), Hospital non-ICU isolation ward (n=1), Hospital COVID isolation ward (n=1), Hospital ICU (n=1), Hospital ER (n=1), Hospital cardiac wards (n=1)]. Whilst the community setting was conducted in a patient's house where individuals were monitored during isolation [Hospital COVID isolation ward and Community setting Patient's house (n=1)].

SARS-CoV-2 contamination results

The largest number of mobile phone's tested for SARS-CoV-2 contamination was 253 [21] and the lowest number was 2 [15] [16]. Across all 15 studies, 511 mobile phones were examined with 231 phones testing positive for the presence of SARS-CoV-2, pertaining to a contamination rate of 45% (**Table 2**).

Study design characteristics

The most frequent confirmation method of SARS-CoV-2 contamination on mobile phones was RNA extraction with PCR (**Table 1).** Additionally, **Table 1** outlines the various RNA extraction kits with PCR protocols utilised amongst the studies. Four studies utilised a Qiagen QiAamp Viral mini kit [15] [19] [23] [24]. Four studies utilised a probe-based PCR kit: QuantiNova Probe RT-PCR kit (Qiagen) [17] (SensiFAST Probe Lo-ROX One-Step kit (Bioline) [18], quantitative PCR (qPCR) Probe Assay) [20] and Promega GoTaq Probe 1-Step RT-qPCR system (A6121) [21]. Two studies utilised a Real Star SARS-CoV-2 Altona kit [19] [23].

Additional kits include used were: Qiagen DSP Virus Spin Kit (QIAGEN GMbH, Hilden, Germany) [12], nucleic acid extraction system (AdvanSureTM E3 System; LG Chem, Seoul,

Korea) [13], rRT-PCR kit (PowerChekTM 2019-nCoV Real-time PCR Kit; KogeneBiotech, Seoul, Korea) [13], SARS-CoV-2 test kit (Allplex 2019-nCoV Assay, Seegene, Seoul, Korea) [16], RNAdvance Viral kit (Beckman Coulter) [18], Viral Nucleic Acid Extraction Kit II (Geneaid Biotechnology) [20], m2000 Abbott Real Time Kit (Abbott, Chicago, IL, USA) [23] and TaqMan® Fast Virus One-Step RT-PCR Master Mix (ABI) [24]. 2 studies did not specify an RNA extraction or PCR protocol [11] [14].

The target genes for PCR amongst all studies include the *ORF-1* gene, *N* gene, *S* gene, *E* gene and *RdRp* gene. Four studies targeted the *ORF-1* and/or *N* genes [10] [14] [15] [22], two studies targeted the *E* gene [12] [18] , one study targeted the *S* and *E* genes [19], one study targeted the *N*, *RdRp*, *S* and *E* genes [23], one study targeted the *RdRp*, *N* and *E* genes [16], one study targeted the *E* and *RdRp* genes [13], one study targeted the *RdRp* gene [17], one study targeted the *N2* gene [21], one study targeted the *E* and *N* genes [24] and 2 studies did not specify the gene targeted through PCR [11] [20].

Eight studies did not specify the cycle threshold of positive SARS-CoV-2 mobile phone samples. Of those that did report a median cycle threshold, the highest Ct (average) value was 44.4 [15] and the lowest Ct (average) value was 24 [23].

Viral cell culture for SARS-CoV-2 viability testing

In total, 5 out of the 15 studies performed a cell culture protocol to confirm the viability and infectivity of the positive SARS-CoV-2 samples obtained from mobile phones. There were 3 out of 5 studies which included a (Ct) medium cycle threshold to perform the viral cell culture experimentation. VERO cells were used to perform the viral viability experiments amongst the studies with VERO E6 cells were used in three studies. One study was able to confirm viral replication through cell culture experimentation [24].

Discussion

This systematic review has detailed a comprehensive investigation of mobile phone contamination with SARS-CoV-2 which is the novel virus responsible for the global COVID-19 pandemic. In total, 15 studies from 10 different countries which met the inclusion criteria were included. The studies included in this current review had reported a wide-range of different fomites potentially contaminated with SARS-CoV-2 but our review only analysed the data related to mobile phone contamination. Therefore, for each study only the total number of

mobile phones tested was reported (both healthcare and patient samples). The average contamination rate of mobile phones with the SARS-CoV-2 virus was found to be 45% across all studies included in the systematic review.

Previous research has highlighted the extent of microbial contamination on mobile phones with studies reporting the presence on phones of different prokaryotic and eukaryotic microorganisms [3] [4] [5] [22] [25] [26] [27] [28]. In 2022, new studies utilised next-generation sequencing on swab samples from mobile phones uncovered diversity of microbial agents contaminating mobile phones with a plethora of antibiotic resistant and virulence factor genes which had previously been undetected with traditional microbiological identification techniques [26] [4]. The scale and number of microbes found on mobile phones naturally bring raise the question of whether mobile phones harbour SARS-CoV-2, and to what extent, as well as decipher if these devices act as fomites facilitating dissemination of SARS-CoV-2. In early 2020, a scoping review by Olsen et al warned that hand washing practices would eliminate viruses in hands, but hands would be cross contaminated again when touching fomite mobile phones, passive vectors spreading infection globally [3]. SARS in 2002, MERS in 2012 and now COVID-19 show a pattern of frequent occurrences of global pandemic proportions facilitated by urbanisation, climate change, modern transport, and incomplete infection control procedures.

With 7.26 billion mobile phones used globally across the world [1], the potential for microbial dissemination acting as fomites is of concern and highlight the need for infection control measures to sanitise these devices (**Infographic 1**). This is even more pertinent as one study has shown that SARS-CoV-2 can remain viable and infectious for a long period of up to days on such surfaces [9]. The studies of this current systematic review are in majority carried out in healthcare settings, which represent as a front-line location in the fight against COVID-19 and findings showed that a large number of tested mobile phones from healthcare workers were positive for SARS-CoV-2 detection. Boucherabine et al 2022 showed that the mobile phone of one of the five healthcare workers in the COVID-19 ward positive SARS-CoV-2 detection despite the report of cleaning the device with alcohol swabs [22]. It is alarming to know that medical staff are readily using mobile phones in bathrooms in grand majority [25] [27]. In 2020, a study in Nebraska investigated the presence of SARS-CoV-2 on 14/18 (77.8%) mobile phones. The authors reported a contamination rate in toilets of more than 80% [12]. Several

pathogens including SARS-CoV-2 are shed in faeces and retrieval of such virus has been reported in numerous publications and found in sewage too [29] [30].

In hospitals, the prevention of nosocomial or hospital-acquired infection is an important strategy for improving the outcomes for inpatients and staff required to care for patients with infectious diseases. There are many studies that considered the importance of early testing, the use of PPE and of cleaning surfaces in managing the risk of nosocomial infection in hospitalised patients with the respiratory syncytial virus prior to the COVID-19 Pandemic [31]. The recognition of the potential importance of the contaminated surface of the mobile phones was not recognised until early 2000. By 2016, 45% of the world's population were reported to own a smart phone [32], but this proportion is now at over 90%. Hence researchers are now recognising the potential of these billions of mobile phones to act as fomites. However, regulations are still very limited and in December 2022, the guidelines regarding clinical deep clean do not list the mobile phone platforms as surfaces to clean [33]. This means that current policies have not acknowledged the need to consider the contaminated surface of the mobile phone as a risk factor for nosocomial infections. The findings of this study have shown that 45% of phones of patients admitted with SARS-COV2 have detectable virus on them. These findings could equally and logically apply to other known respiratory viruses where nosocomial infections have been recognised. Nosocomial infections include many other pathogens than just respiratory viruses with many bacterial infections caused by contaminated medical devices such as intravenous lines, central lines, intravenous equipment, and various pieces of equipment used in intensive care. Such contaminations are all recognised to cause potential infections and are highlighted as being important to clean in the recent 2022 guidelines. It is in this context, it is important for the healthcare authorities to consider the surface of the mobile as important fomites. Their high rate of utilisation in healthcare settings pose a risk for nosocomial diseases and staff habits to use these devices in toilet may enhance such levels of microbial contamination and microbial propagation. Medical staff possessing mobile phones walk all over the hospital from wards-to-wards and may disseminate microbes more than patients.

Interestingly, mobile phones have been identified as non-invasive screening tool to confirm whether an individual is positive for COVID-19 [The Phone Screen Testing (PoST)]. In that study, Young et al. demonstrated that 81.3-100% of positive cases for SARS-CoV-2 had their mobile phones also testing positive via the PoST system [21]. The notion of utilising mobile

phones as a screening tool for identifying SARS-CoV-2 positive individuals is based on the premise that there is a concordance between microbes found on the hands of individuals and those contaminating their mobile phones. [34].

Since there is a high occurrence of contamination of mobile phones with SARS-CoV-2, there is an urgent need for the development and implementation of sanitation protocols for mobile. Currently available solutions include ultraviolet-C sanitisers with rapid germicidal effect in ten seconds (10s) [35]. These UV-C devices could be incorporated as elements of infection control protocols and offer a practical solution to sanitise mobile phones (sort of a third hand) of staff, patients and visitors in hospitals and other medical settings. Indeed, UV-C emitted phone sanitisers could be included in the 5 moments of hand hygiene, like a "6 moment', to optimise the fight against nosocomial infections (**Infographic 2**). Indeed, findings from a survey-based study consisting of 377 healthcare workers indicated that almost half of the respondents agree that ultraviolet phone sensitisation policy can prevent SARS-CoV-2 dissemination [27].

Study Limitations

The main limitation of the current published literature is the small sample size of mobile phones reported in several publications. Majority of the studies (n/N=12/15) contained had less than 30 mobile phone swab samples. Differing sample collection methodologies and transport of viral samples may reduce the abundance of RNA present prior to RNA extraction. In terms of viral isolation, 10 studies did not include a viral isolation test to investigate infectivity of the SARS-CoV-2 virus recovered from mobile phone swabs. Furthermore, all the studies which performed viral cultivation experiments were unable to confirm viral replication. Nonetheless, one study found evidence for the presence of replication competent virus from cell culture experimentation [12]. An additional study [19] states that whilst high C_{ts} values were observed, the corresponding viral loads were low which may have been caused by several factors including i) freezing and thawing samples, ii) deterioration of the virus due to handling of mobile phones with fingers pre-treated with alcohol sanitisers applied on hands. Furthermore, whilst the studies utilised similar identification methods of RNA extraction and PCR, the sensitivities and specificities of these techniques may have varied from laboratories to laboratories and country to country.

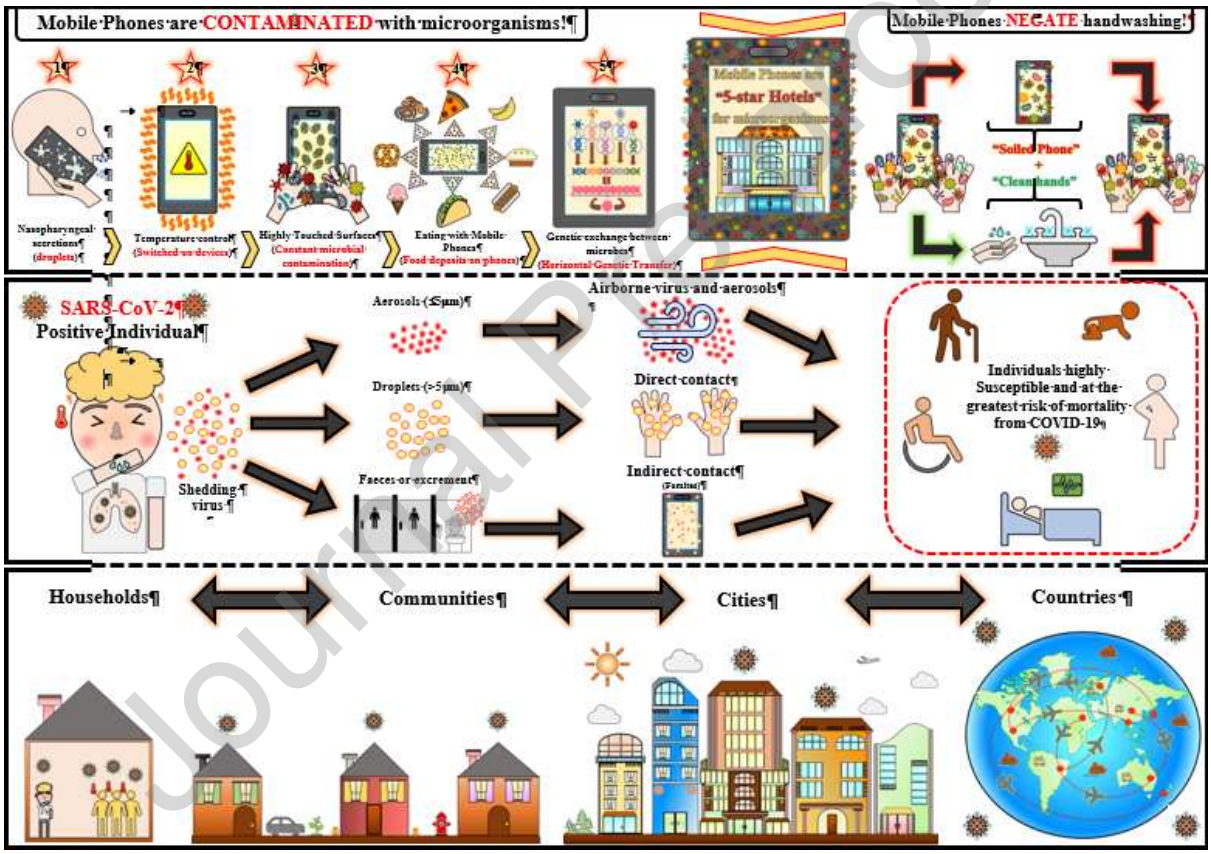
Conclusion

This is the first systematic review to focus on mobile phone contamination with the SARS-CoV-2 the novel corona virus responsible for the COVID-19 pandemic. Since the inception of COVID-19, 15 publications from 10 different countries have reported on the presence of SARS-CoV-2 on mobile phones. As calculated in this systematic review, the average contamination rate of mobile phones sampled from environments containing positive SARS-CoV-2 patients is 45%. The United States Centre for Disease Control and Prevention (CDC) estimate that up to 80% of all infectious disease is transmitted via hands. Mobile phones as high touch ubiquitous devices and contaminated platforms pose significant risk to human health for microbial dissemination and in pandemics. The consensus message across all studies investigated in this review, is the need for universal policy in infection control guidelines towards using mobile phones. Biotechnology companies have developed solutions to decontaminate mobile phones using ultraviolet-C germicidal sanitisers. The integration of these mobile phone sanitisers close to handwashing stations is paramount to prevent infection spread. Contaminated mobile phones negate hand washing and implementing automatic, fast phone sanitisation in hospitals, airports, cruise ships, restaurants, child-care/aged-care facilities and other 'high-risk' environments might prevent infectious diseases spread and save a considerable amount of money to the public health, health care system and beyond (e.g., Biosecurity).

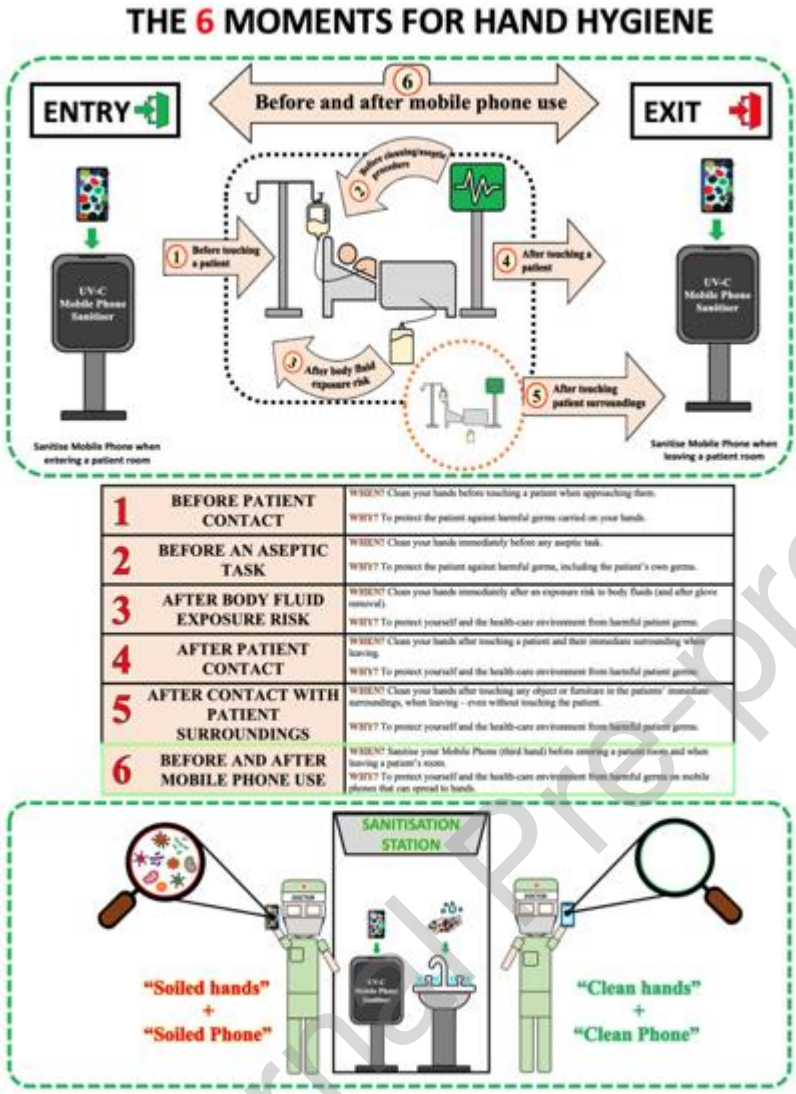
Author's Recommendations

The prospect for mobile phones to contributing to the spread of SARS-CoV-2 within the community, health settings and countries is a reality as we found that 45% of phones harbour the presence of the virus. Mobile phones are poorly decontaminated and sanitised but are used extensively by staff within hospitals, clinics, dentist practices, supermarkets, restaurants, fast food, abattoirs, fruit picking, age care, kindies and used in all public settings from toilets, kitchens, airports, planes, trains, buses etc. While the gold standard hand washing saves live in millions every year, a campaign actively promoted with success by the WHO, mobile phones acting as 'dirty' third hands negate inadvertently our two other biological hands. This alone should immediately alarm medical staff working in infection control. The "6th" moment of hand washing that we provide in our review is vital given the extent of mobile phone use in these settings. Enhancing hospital abilities to respond to infection control to fight nosocomial and healthcare associated infections, and to fight pandemics is a liability for all hospitals in the world [36]. Dissemination risk associated with contaminated mobile phones with fungi,

bacteria or viruses can be dramatically reduced by implementing for example technology driven fast and efficient sanitising devices such as UV-C phone sanitisers in airports and public spaces. The United Nations statement "*Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks*" corresponds to the Sustainable Development Goal #3 section D, a target aimed by 2030. Today in 2023, seven years before that UN SDG#3, it is time to act to prevent billions of high touch mobile phones microbial contaminated platforms from negating the gold standard hand washing in the hands of billions of people in public and medical settings.



Infographic 1. First row: Mobile phones are "5-star hotels" with droplet and food deposition; Warm and constantly contaminated with soiled hands with all sorts of microbes including superbugs. Mobile phones negate hand washing. Row 2. Sars-CoV-2 infected individuals shed their viruses via aerosols/droplets, direct and indirect contact. Row 3. Spread of SARS-CoV-2 is dynamic and fast propagating around the world.



Infographic 2. Mobile phones as the "6th moment of hand hygiene" in healthcare settings. Mobile phones should undergo UV-C sanitisation via high-grade certified UV-C phone sanitises when devices are bought into a patient's room and when they are taken out of a patient's room. Additionally, several UV-C phone sanitisations should be made available in different wards for personal to sanitise frequently their mobile devices.

References

[1] Turner A. How many smartphones are in the world?. Servamus Community-based Safety and Security Magazine 2022 Oct 1;115(10):76-79.

[2] Winnick M. Putting a Finger on Our Phone Obsession. 2016; Available at: https://blog.dscout.com/mobile-touches.

[3] Olsen M, Campos M, Lohning A, Jones P, Legget J, Bannach-Brown A, et al. Mobile phones represent a pathway for microbial transmission: A scoping review. Travel medicine and infectious disease 2020 May;35:101704.

[4] Olsen, M., Nassar, R., Senok A., Moloney, S., Lohning, A., Jones, P., Grant, G., Morgan, M., Palipana, D., McKirdy S., Alghafri, R., Tajouri, L. (2022) Mobile phones are hazardous microbial platforms warranting robust public health and biosecurity protocols. *Scientific reports* **12**, [10009]. https://doi.org/10.1038/s41598-022-14118-9

[5] Tajouri L, Campos M, Olsen M, Lohning A, Jones P, Moloney S, et al. The role of mobile phones as a possible pathway for pathogen movement, a cross-sectional microbial analysis. Travel medicine and infectious disease 2021 Sep;43:102095.

[6] Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. The Lancet infectious diseases 2020 May;20(5):533-534.

[7] McCalla S, Thomas R, Reilly M. Hand Hygiene Compliance: "Going Back to Basics". American journal of infection control 2014;42(6):S134.

[8] De Groote P, Blot K, Conoscenti E, Labeau S, Blot S. Mobile phones as a vector for Healthcare-Associated Infection: A systematic review. Intensive & critical care nursing 2022 Oct 1,;72:103266.

[9] Riddell S, Goldie S, Hill A, Eagles D, Drew TW. The effect of temperature on persistence of SARS-CoV-2 on common surfaces. Virology journal 2020 Oct 7,;17(1):1-145.

[10] Ma J, Qi X, Chen H, Li X, Zhang Z, Wang H, et al. Coronavirus Disease 2019 Patients in Earlier Stages Exhaled Millions of Severe Acute Respiratory Syndrome Coronavirus 2 Per Hour. Clinical infectious diseases 2021 May 18,;72(10):e652-e654.

[11] Li YH, Fan YZ, Jiang L, Wang HB. Aerosol and environmental surface monitoring for SARS-CoV-2 RNA in a designated hospital for severe COVID-19 patients. Epidemiology & Infection 2020 July 8,;148:e154.

[12] Santarpia JL, Rivera DN, Herrera VL, Morwitzer MJ, Creager HM, Santarpia GW, et al. Aerosol and surface contamination of SARS-CoV-2 observed in quarantine and isolation care. Scientific reports 2020 Jul 29,;10(1):12732.

[13] Kim UJ, Lee SY, Lee JY, Lee A, Kim SE, Choi OJ, et al. Air and Environmental Contamination Caused by COVID-19 Patients: a Multi-Center Study. Journal of Korean medical science 2020 Sep 8,;35(37):e332.

[14] Wei L, Huang W, Lu X, Wang Y, Cheng L, Deng R, et al. Contamination of SARS-CoV-2 in patient surroundings and on personal protective equipment in a non-ICU isolation ward for COVID-19 patients with prolonged PCR positive status. Antimicrobial resistance & infection control 2020 Oct 29,;9(1):167.

[15] Lei H, Ye F, Liu X, Huang Z, Ling S, Jiang Z, et al. SARS-CoV-2 environmental contamination associated with persistently infected COVID-19 patients. Influenza and Other Respiratory Viruses 2020 Nov;14(6):688-699.

[16] Shin KS, Park HS, Lee J, Lee JK. Environmental surface testing for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) during prolonged isolation of an asymptomatic carrier. Infection Control & Hospital Epidemiology 2020 Nov 1,;41(11):1328-1330.

[17] Cheng VC, Wong S, Chan VW, So SY, Chen JH, Yip CC, et al. Air and environmental sampling for SARS-CoV-2 around hospitalized patients with coronavirus disease 2019 (COVID-19). Infection Control & Hospital Epidemiology 2020 Nov 1,;41(11):1258 1265.

[18] Ben-Shmuel A, Brosh-Nissimov T, Glinert I, Bar-David E, Sittner A, Poni R, et al. Detection and infectivity potential of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) environmental contamination in isolation units and quarantine facilities. Clinical microbiology and infection 2020 Dec 1,;26(12):1658-1662.

[19] Espinoza EPS, Cortes MF, Noguera SV, Paula AVd, Guimarães T, Boas LSV, et al. Are mobile phones part of the chain of transmission of SARS-CoV-2 in hospital settings? Revista do Instituto de Medicina Tropical de São Paulo 2021 Jan 1,;63:e74.

[20] Elbadawy HM, Khattab A, Alalawi A, Dakilallah Aljohani F, Sundogji H, Mahmoud AS, et al. The detection of SARS-CoV-2 in outpatient clinics and public acilities during the COVID-19 pandemic. Journal of medical virology 2021 May;93(5):2955-2961.

[21] Young RM, Solis CJ, Barriga-Fehrman A, Abogabir C, Thadani AR, Labarca M, et al. Smartphone screen testing, a novel pre-diagnostic method to identify SARS-CoV-2 infectious individuals. eLife 2021 Jun 21,;10.

[22] Boucherabine S, Nassar R, Zaher S, Mohamed L, Olsen M, Alqutami F, et al. Metagenomic Sequencing and Reverse Transcriptase PCR Reveal That Mobile Phones and Environmental Surfaces Are Reservoirs of Multidrug-Resistant Superbugs and SARS-CoV-2. Frontiers in cellular and infection microbiology 2022 Mar 8,;12:806077

[23] Nagle S, Tandjaoui-Lambiotte Y, Boubaya M, Athenaïs G, Alloui C, Bloch-Queyrat C, et al. Environmental SARS-CoV-2 contamination in hospital rooms of patients with acute COVID-19. The Journal of hospital infection 2022 Aug 1,;126:116-122.

[24] Leal J, O'Grady HM, Armstrong L, Dixit D, Khawaja Z, Snedeker K, et al. Patient and ward related risk factors in a multi-ward nosocomial outbreak of COVID-19: Outbreak investigation and matched case-control study. Antimicrobial resistance & infection control 2023 Mar 22,;12(1):21.

[25] Olsen M, Lohning A, Campos M, Jones P, McKirdy S, Alghafri R, et al. Mobile phones of paediatric hospital staff are never cleaned and commonly used in toilets with implications for healthcare nosocomial diseases. Scientific reports 2021 Jun 21,;11(1):12999.

[26] Olsen M, Nassar R, Senok A, Albastaki A, Leggett J, Lohning A, et al. A pilot metagenomic study reveals that community derived mobile phones are reservoirs of viable pathogenic microbes. Scientific reports 2021 Jul 8,;11(1):14102.

[27] A. Albastaki, M. Olsen, H. Almulla et al., Mobile phones as fomites for pathogenic microbes: A cross-sectional survey of perceptions and sanitization habits of healthcare workers in Dubai, United Arab Emirates, Infection, Disease & Health, 2022 July. https:// doi.org/10.1016/j.idh.2022.07.001

[28] Boucherabine S, Nassar R, Mohamed L, Olsen M, Alqutami F, Zaher S, et al. Healthcare Derived Smart Watches and Mobile Phones are Contaminated Niches to Multidrug Resistant and Highly Virulent Microbes. Infection and Drug Resistance 2022 Aug 17,;15:5289–5299.

[29] Huang Y, Ding Z, Chen Q, Wu L, Guo L, Zhao C, et al. Environmental virus detection associated with asymptomatic SARS-CoV-2-infected individuals with positive anal swabs. The Science of the total environment 2021 Jan 20,;753:142289.

[30] Foladori P, Cutrupi F, Segata N, Manara S, Pinto F, Malpei F, et al. SARS-CoV-2 from faeces to wastewater treatment: What do we know? A review. The Science of the total environment 2020 Nov 15,;743:140444.

[31] French CE, McKenzie BC, Coope C, Rajanaidu S, Paranthaman K, Pebody R, et al. Risk of nosocomial respiratory syncytial virus infection and effectiveness of control measures to prevent transmission events: a systematic review. Influenza and other respiratory viruses 2016 Jul;10(4):268-290.

[32] Zippia. "20 Vital Smartphone Usage Statistics [2023]: Facts, Data, and Trends On Mobile Use In The U.S." Zippia.com. Apr. 3, 2023, http://www.zippia.com/advice/smartphone-usage-statistics/

[33] Australian Government. Department of Health and Aged Care -Cleaning and disinfection for health and residential care facilities Infection Prevention and Control Expert Group - Cleaning and disinfection for health and residential care facilities. 2022 Oct 25., https://www.health.gov.au/sites/default/files/2022-12/coronavirus-covid-19-environmental-cleaning-and-disinfection-principles-for-health-and-residential-care-facilities.pdf

[34] Meadow JF, Altrichter AE, Green JL. Mobile phones carry the personal microbiome of their owners. PeerJ 2014 Jun 24,;2:e447.

[35] Olsen M, Goldsworthy A, Nassar R, Senok A, Albastaki A, Lee ZZ, et al. Ultraviolet-C-Based Mobile Phone Sanitisation for Global Public Health and Infection Control. Microorganisms 2023 -07-25;11(8).

[36] World Health Organization. (2014). Hospital preparedness for epidemics. World Health Organization. https://apps.who.int/iris/handle/10665/151281

Declaration of Competing Interest

No conflict of interest to declare