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ORIGINAL ARTICLE

Transfer of Phi6 bacteriophage between human skin and surfaces common to consumer-facing environments

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Abstract

Aims: This study aimed to determine the extent of Phi6 (Φ6) transfer between skin and surfaces relevant to consumer-facing environments based on inoculum matrix, surface type and contact time.

Methods and Results: Φ6 transfer rates were determined from skin-to-fomite and fomite-to-skin influenced by inoculum matrix (artificial saliva and tripartite), surface type (aluminium, plastic, stainless steel, touchscreen, vinyl and wood) and contact time (5 and 10 s). Significant differences in estimated means were observed based on surface type (both transfer directions), inoculum matrix (skin-to-fomite) and contact time (both transfer directions). During a sequential transfer experiment from fomite-to-skin, the maximum number of consecutive transfer events observed was 3.33 ± 1.19, 2.33 ± 1.20 and 1.67 ± 1.21 for plastic, touchscreen and vinyl, respectively.

Conclusions: Contact time significantly impacted Φ6 transfer rates, which may be attributed to skin absorption dynamics. Surface type should be considered for assessing Φ6 transfer rates.

Significance and Impact of the Study: Although the persistence of Φ6 on fomites has been characterized, limited data are available regarding the transfer of Φ6 among skin and fomites. Determining Φ6 transfer rates for surfaces in consumer-facing environments based on these factors is needed to better inform future virus transmission mitigation strategies.

KEYWORDS
fomite, Phi6, SARS-CoV-2, surrogate, transfer

INTRODUCTION

The persistence of Phi6 (Φ6) on fomites has been characterized (Baker et al., 2022; Bangiyev et al., 2021; Fedorenko et al., 2020; Gallandat & Lantagne, 2017; Whitworth et al., 2020; Wood et al., 2020). Likewise, studies assessing the transfer rates for viruses (e.g. Hepatitis A, influenza A, MS2 coliphage, poliovirus 1) between human skin and surfaces have been reported (Ansari et al., 1988; Bean et al., 1982; Julian et al., 2010; Kotwal & Cannon, 2014; Lopez et al., 2013; Mbithi et al., 1992; Stephens et al., 2019; Zhao & Li, 2021), although there are limited data on Φ6 interaction with skin and fomites (Anderson & Boehm, 2021).

Anderson and Boehm (2021) were the first to evaluate Φ6 transfer between skin and fomites. These authors tested different surface types (stainless steel, plastic and painted wood) and measured both transfer rates from fomites and transfer rates to fomites. Anderson and Boehm (2021) observed significant differences in transfer

rate based on surface type, yet no significant difference was observed based on transfer direction. Further evaluation of additional surfaces, inoculum matrices and contact time is warranted to characterize Φ6 and validate this bacteriophage as a potential surrogate for future studies involving SARS-CoV-2 variants as well as emerging enveloped viruses (Baker et al., 2022).

Although specific criteria need to be met to adopt a surrogate organism as a model for a set of pathogens (Sinclair et al., 2012), lipid-enveloped bacteriophage Φ6 has been investigated to simulate Ebola viruses (Gallandat & Lantagne, 2017; Whitworth et al., 2020; Wood et al., 2020) and more recently to conduct SARS-CoV-2-based research (Baker et al., 2022; Bangiyev et al., 2021; Fedorenko et al., 2020). Φ6 is a lipid-enveloped, segmented double-stranded RNA bacteriophage with spiked proteins that is similar in size to SARS-CoV-2 at approximately 75 nm in diameter (Fedorenko et al., 2020; Gonzalez et al., 1977). The host of Φ6 is *Pseudomonas syringae* pathovar *phaseolicola*. Both host and Φ6 have BSL-1 status, which enables cost-effective research to be performed without specialized facilities, making Φ6 an attractive model for many different pathogens (Aquino de Carvalho et al., 2017).

Risk of virus transmission via indirect contact is impacted by the transfer rate from surfaces-to-hands followed by a transfer event (i.e. self-inoculation) from hands-to-face (Pitol & Julian, 2021). Transfer rates are needed to further evaluate the utility of Φ6 as a surrogate for SARS-CoV-2 as well as future emerging viruses of public health importance (Anderson & Boehm, 2021). The purpose of this study was to determine the extent of Φ6 transfer between skin and surfaces relevant to consumer-facing environments based on inoculum matrix, surface type and contact time. Determining Φ6 transfer rates among surfaces in consumer-facing environments based on these factors is needed to better inform future virus transmission mitigation strategies.

MATERIALS AND METHODS

Φ6 production

Φ6 bacteriophage (HER102) production and *P. syringae* pathovar *phaseolicola* (Pph) (HER1102) growth was performed with lysogeny (LC) broth (10 g NaCl [VWR], 10 g tryptone [VWR], 5 g yeast extract [VWR] L^{-1} ultrapure water, pH adjusted to 7.5) as previously described (Baker & Gibson, 2021). Φ6 stock was produced by adding Pph (200 µl) and Φ6 (100 µl [at approximately 10 log plaque-forming units, PFU ml^{-1}]) to 5 ml of LC soft agar, which was poured onto LC agar plates via the double agar overlay assay (DAL) (Kropinski et al., 2009). Solidified plates were incubated at 25°C for 20–24 h, and soft agar from lacy-webbed plates was collected with a 25 cm cell scraper (VWR), vortexed, centrifuged (10 min at 3000 *g*, 4°C), and supernatant was filtered (0.45 µm sterile polyethersulfone syringe filter; Whatman) and stored at 4°C until use.

Inoculum preparation

Φ6 stock was diluted to obtain inoculum levels of approximately 9 log PFU ml^{-1}. Two separate inoculum matrices were developed: artificial saliva and tripartite. Artificial saliva consisted of 1.54 mM KH_2PO_4 (Sigma-Aldrich), 2.46 mM K_2HPO_4 (Fisher Scientific), 0.04 mg L^{-1} $MgCl_2 \cdot 7H_2O$ (Alfa Aesar), 0.11 g L^{-1} NH_4Cl (VWR), 0.12 g L^{-1} $(NH_2)_2CO$ (VWR), 0.13 g L^{-1} $CaCl_2$ (VWR), 0.19 g L^{-1} KSCN (Acros Organics), 0.42 g L^{-1} $NaHCO_3$ (Fisher Scientific), 0.88 g L^{-1} NaCl (VWR), 1.04 g L^{-1} KCl (VWR) and 3 g L^{-1} mucin (Sigma-Aldrich) at pH 7 (ASTM, 2016; Owen et al., 2021). Tripartite was prepared as per international standard ASTM E2197-17 and consisted of 0.8 g L^{-1} bovine mucin (Sigma-Aldrich), 2.5 g L^{-1} bovine serum albumin (VWR) and 3.5 g L^{-1} tryptone (VWR) to mimic fluids shed by infected individuals (ASTM, 2017b; Kasloff et al., 2021; Riddell et al., 2020; Sattar et al., 2003).

Surface and skin preparation

Six surface types (aluminium, plastic, stainless steel, touchscreen, vinyl and wood) at 5 × 5 cm (25 cm^2) were prepared as previously described (Baker et al., 2022). Briefly, aluminium, plastic, stainless steel and touchscreen were sprayed with 70% ethanol, washed with hot, soapy water, thoroughly rinsed with DI water and dried. Stainless steel, aluminium and touchscreen surfaces were wrapped in aluminium foil and steam-sterilized at 121°C, 15 psi for 30 min. Prior to transfer trials, each surface type was exposed to UV light in a biosafety cabinet (30 min).

Thumbpads were prepared as previously described with modifications (Baker & Gibson, 2021). Briefly, hands were washed with liquid hand soap (Equate; Wal-Mart Stores, Inc.) for 30 s, rinsed thoroughly and dried with paper towels before being sprayed with 70% ethanol and air-dried. Thumb- or fingerpads were demarcated with a sterile 2 ml plastic centrifuge tube (9 mm diameter) by pressing the tube opening firmly on the skin for 15 s (Ansari et al., 1988). Following transfer events, skin was wiped with an 70% ethanol soaked Kimwipes (Kimtech Science), and hands were washed and sprayed with 70% ethanol as previously described prior to subsequent transfer events. A single volunteer was used for all studies.

Thumbpad-to-surface transfer (Study 1)

Demarcated thumbpads were inoculated with 2 μl of Φ6, and immediately (<15 s) pressed to a surface placed on a triple beam balance scale (Ohaus® Harvard Trip Balance) set to 800 g pressure (Zhao & Li, 2019). The six surface types were used in a different order for each trial to minimize the impact of handwashing frequency on transfer rates (Kownatzki, 2003). Thumbpads were used from each hand to facilitate a simultaneous evaluation of two contact times (5 and 10 s) following each handwashing/skin preparation. After each transfer event, Φ6 was recovered from the surface using 2 ml of LC broth with repeated pipetting (five times). Then, the eluent was transferred to a sterile 2 ml centrifuge tube, diluted and plated in duplicate on LC agar via the DAL method, as previously described, to determine the Φ6 concentration.

To determine the Φ6 concentration on thumbpads prior to transfer events for each trial, 2 μl of Φ6 was inoculated onto a thumbpad and recovered as per international standard ASTM E1838-17 by rubbing for 1 min with moderate pressure in a mini dish (35×10 mm) (VWR) containing 2 ml of LC broth (ASTM, 2017a). The eluent was transferred to a sterile 2 ml tube, diluted and plated via the DAL method, as previously described. Negative controls were performed for each trial by depositing 2 μl of LC buffer on thumbpads, transferring to surfaces, recovering eluent and plating as previously described to ensure viral absence. Only one trial was performed in a single day, which included an assessment of each surface ($n = 6$) and contact time ($n = 2$) for either artificial saliva or tripartite as an inoculum matrix.

Surface-to-thumbpad transfer (Study 2)

Two microliters of Φ6 was deposited on the center of a given surface, and thumbpads were immediately (<15 s) placed on the inoculated surface for 5 or 10 s contact time at 800 g pressure. Similar to Study 1, the six surface types were evaluated in a different order for each trial to minimize the impact of handwashing frequency on transfer rates. Following each transfer event, Φ6 was eluted from the thumbpad by rubbing in a mini dish containing 2 ml of LC broth for 1 min with moderate pressure, and the eluent was assayed as previously described. The inoculum concentration was used to calculate the amount of Φ6 on surfaces prior to transfer events. Negative controls were performed for each trial by depositing 2 μl of LC buffer on surfaces, contacting thumbpads on the surface, recovering from thumbpads and plating the eluent to ensure viral absence. Artificial saliva or tripartite matrices were evaluated in a single trial per day for each surface and contact time as described in Study 1.

Sequential transfer from surface-to-fingerpad (Study 3)

Two microliters of Φ6 was deposited on the center of a given surface, and the left index finger was immediately (<15 s) placed on the inoculated surface for 10 s contact time at 800 g pressure. Following the first transfer event, the left middle finger was placed on the contaminated surface, and a transfer event was repeated for 10 s. This process was repeated to result in six total transfer events with the middle three fingers of each hand. Immediately following the last transfer event, fingerpads were simultaneously placed into six separate mini dishes containing 2 ml of LC broth, and Φ6 was recovered as previously described. Vinyl, plastic and touchscreen surfaces were investigated during Study 3 in a different order for each trial with artificial saliva as the inoculum matrix. A presence/absence assay was performed via the DAL method by plating 0.5 ml of the undiluted eluent, in duplicate. The limit of detection for Study 3 was 0.3 log PFU.

Statistical analysis

Three experimental trials were performed for each inoculum matrix in Studies 1 and 2, and three trials were performed in Study 3 with artificial saliva as the inoculum matrix for plastic, touchscreen and vinyl surfaces. In Studies 1 and 2, the Φ6 transfer rate was calculated as the ratio of the infectious virus quantity transferred to the infectious virus quantity added to the surface or thumbpad. Statistical analysis was applied to determine if inoculum matrix, surface type, and contact time are significant predictors of the Φ6 transfer rate. Data were first analysed using a linear model. The residual analysis demonstrated that the assumptions of normality and homoscedasticity were not verified because the Φ6 transfer rate followed a binomial distribution, and the number of observations was not sufficient to consider that the sample means were approximately normally distributed (central limit theorem). The data were then analysed using a generalized linear model (GLM) with binomial errors. The GLM residual deviance was greater than the residual degrees of freedom, which indicated that the GLM underestimated the variance of the Φ6 transfer rate. The data were then analysed again using a GLM with quasibinomial errors to account for overdispersion and maximize the GLM goodness-of-fit. This GLM relates the Φ6 transfer rate to the inoculum matrix, surface type and contact time using the logit link

function. The estimated treatment means were converted back into Φ6 transfer rates using Equation (1):

$$\Phi 6_{ijk} = \frac{1}{1 + \frac{1}{e^{\mu_{ijk}}}} \quad (1)$$

where $\Phi 6_{ijk}$ is the estimated Φ6 transfer rate for inoculum matrix i, surface type j and contact time k; and m_{ijk} is the estimated treatment means for the same treatment combination. Only the results from the GLM with quasibinomial errors were reported in this manuscript.

In Study 3, statistical analysis was applied to determine if surface type affects the number of consecutive positive Φ6 transfers from surface to thumbpad. Data were first analysed using a linear model. The residual analysis demonstrated that the assumptions of normality and homoscedasticity were not verified because the number of consecutive positive Φ6 transfers from surface to thumbpad followed a geometric distribution, and the number of observations was not sufficient to consider that the sample means were approximately normally distributed. The data were then analysed using a GLM with geometric errors. This GLM relates the number of consecutive positive Φ6 transfer rates to surface type using the log link function. The estimated treatment means were converted back into Φ6 transfer rates using Equation (2):

$$\Phi 6_j = e^{\mu_j} \quad (2)$$

where $\Phi 6_j$ is the estimated sequential Φ6 transfer rate for surface type j and m_j is the estimated treatment means for surface type j. Only the results from the GLM with geometric errors were reported in this manuscript. In all studies, treatment means and associated 95% confidence intervals (CIs) were determined using estimated marginal means. Statistical differences between treatment means were evaluated using multiple comparisons and represented using compact letter display. The data were analysed in R (R Core Team, 2021) using *base*, *ggplot2* (Wickham, 2016), *ggpubr* (Kassambara, 2020), *car* (Fox & Weisberg, 2019), *emmeans* (Length, 2021) and *multcomp* (Hothorn et al., 2008) packages.

RESULTS

Transfer impacted by inoculum matrix

Raw data values were plotted based on inoculum matrix to observe the distribution of skin-to-fomite and fomite-to-skin transfer rates among all trials (Figure S1). The main effect of inoculum matrix was a significant predictor of Φ6 transfer rate from skin-to-fomite ($p < 0.001$). The estimated transfer rate from skin-to-fomite for artificial saliva and tripartite was 9.73% (95% CI, 2.59, 30.5) and 1.84% (95% CI, 0.40, 8.01) respectively. From fomite-to-skin, no significant differences in transfer rates were observed based on inoculum matrix at 4.72% (95% CI, 3.66, 6.07) and 4.56% (95% CI, 3.52, 5.89) for artificial saliva and tripartite matrices, respectively ($p > 0.05$).

Transfer influenced by contact time

The main effect of contact time was a significant predictor of Φ6 transfer rate from skin-to-fomite ($p < 0.001$) as well as from fomite-to-skin ($p < 0.05$). In Study 1, the Φ6 skin-to-fomite transfer rate was higher at 5 s versus 10 s contact time with estimated means of 7.71% (95% CI, 1.98, 25.7) and 2.36% (95% CI, 0.54, 9.81), respectively. In Study 2, the Φ6 fomite-to-skin transfer rate was higher at 10 s versus 5 s contact time, with estimated means of 5.65% (95% CI, 4.47, 7.11) and 3.80% (95% CI, 2.86, 5.02), respectively (Figure 1).

Transfer based on surface type

The main effect of surface type was a significant predictor of Φ6 transfer rate from skin-to-fomite ($p < 0.001$) as well as from fomite-to-skin ($p < 0.01$). In Study 1, the highest Φ6 skin-to-fomite transfer rate was observed on touchscreen [22.0% (95% CI, 12.8, 35.0)], followed by aluminium [17.5% (95% CI, 9.64, 29.7)], vinyl [10.9%, (95% CI, 5.29, 21.3)], plastic [7.02% (95% CI, 2.83, 16.4)], stainless steel [2.5%, (95% CI, 0.68, 9.03)] and wood [0.06% (95% CI, 1.73e-5, 65.3)] (Figure 1). In Study 2, the highest Φ6 fomite-to-skin transfer rate was observed with aluminium, plastic and stainless steel at 6.83% (95% CI, 4.77, 9.69), 6.60% (95% CI, 4.57, 9.41) and 6.03% (95% CI, 4.11, 8.76), respectively. The Φ6 fomite-to-skin transfer rates for vinyl, touchscreen and wood were 4.69% (95% CI, 3.03, 7.19) and 4.1% (95% CI, 2.56, 6.47) and 1.87% (95% CI, 0.93, 3.71), respectively.

Sequential transfer of Φ6 in artificial saliva from fomite-to-skin

When assessing the number of sequential transfer events from contaminated vinyl, touchscreen and plastic surfaces, there were significant differences between plastic and vinyl but not between vinyl and touchscreen or plastic and touchscreen ($p < 0.05$) (Figure 2). Overall, the highest number of transfer events was observed for plastic (3.33 ± 1.19), followed by touchscreen (2.33 ± 1.20) and vinyl (1.67 ± 1.21).

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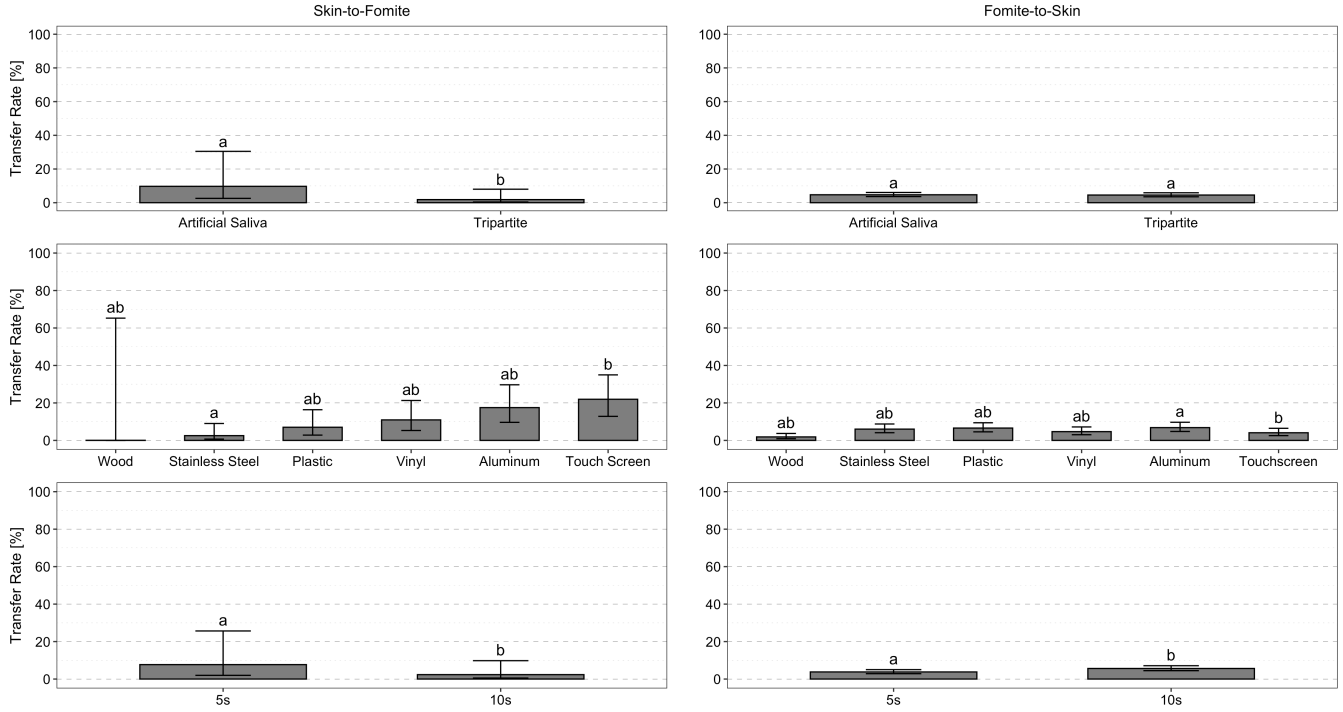
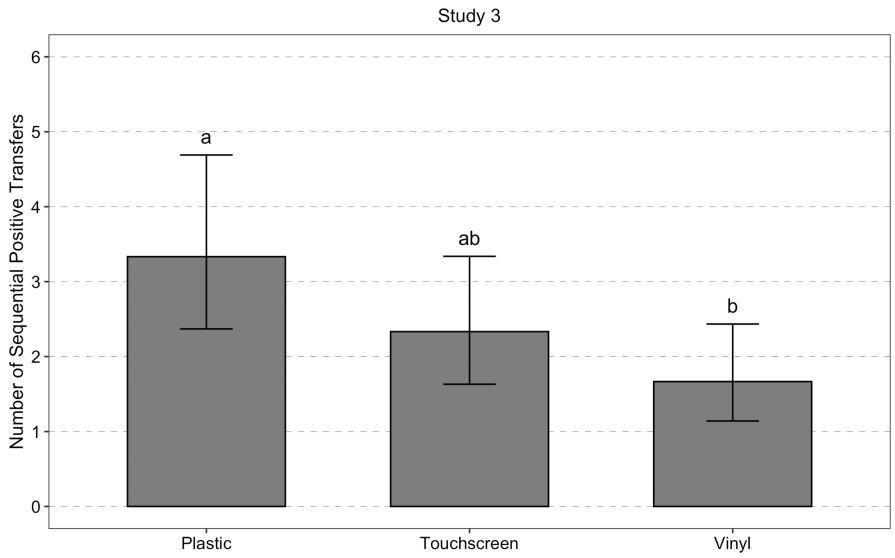


FIGURE 1 Transfer rates (%) obtained from generalized linear model from skin-to-fomite (Study 1) (top left, middle left, bottom left) and from fomite-to-skin (Study 2) (top right, middle right, bottom right) based on organic load (top left, top right), surface type (middle left, middle right) and contact time (bottom left, bottom right). Within each figure, different letters indicate significant differences between factors ($p < 0.05$). Error bars represent the 95% confidence intervals of the estimated mean.

FIGURE 2 Number of sequential positive transfers on plastic, touchscreen and vinyl. Trials were performed with artificial saliva as the inoculum matrix with a contact time of 10 s for each transfer event (six consecutive transfer events). Different letters indicate significant differences between factors ($p < 0.05$). Error bars represent standard deviations of the mean.



DISCUSSION

Many studies on virus transfer have been performed with nonpathogenic viruses or surrogates, as virus transfer between human skin and surfaces is difficult to establish for BSL-2, or higher, pathogens. Φ6 has emerged as a surrogate to study enveloped viral pathogens including SARS-CoV-2 due to structural similarities and BSL-1 status. Anderson and Boehm (2021) were the first to characterize Φ6 transfer between human skin and surfaces. The current study was performed to characterize the transfer rates of Φ6 to and from human skin based on inoculum matrix, surface type and contact time.

Anderson and Boehm (2021) determined the transfer rate of Φ6 among stainless steel, plastic and painted wood using the fingerpads of volunteers. With a 10 s contact time at 500 g pressure and a tryptic soy broth inoculum matrix, mean transfer rates among all surfaces ranged from 7% to 22% from fingerpad to surface (5 min wait after inoculation) and 5%–28% from surface to fingerpad

(30 min wait after inoculation). No significant difference was observed based on transfer direction. However, significant differences in transfer rates were observed between wood and stainless steel as well as wood and plastic, but not plastic and stainless steel. Overall, a mean transfer rate of 17% was observed between each surface and transfer direction for Φ6 (Anderson & Boehm, 2021). Julian et al. (2010) observed a difference in virus transfer rates based on transfer direction, although this was impacted by the phage type under investigation (MS2, fr and qX174), thus complicating potential explanations for how transfer direction impacts transfer rates (Ansari et al., 1991; Mbithi et al., 1992). Zhao and Li (2021) developed a model to evaluate how various factors impact transfer rates, which suggests that touch force and inoculation volume are positively correlated with virus transfer, while donor roughness (i.e. human skin), surface hardness, temperature and surface inoculation area are negatively correlated with virus transfer.

In this study, significant differences in estimated means were observed based on surface type (both transfer directions), inoculum matrix (skin-to-fomite) and contact time (both transfer directions). This study was performed immediately after inoculation; thus, a wet surface inoculum was evaluated throughout the study. A wet inoculum was evaluated in this study due to the limited data available on wet inoculum transfer, which was decided after observing minimal differences in transfer between wet and dry (~10 min wait time) during preliminary trials. Despite the presence of a wet inoculum during transfer, the current study observed similar transfer rates to Anderson and Boehm (2021), in which inoculum was allowed to dry for up to 30 min.

Contact time impacted transfer rates significantly regardless of transfer direction. However, the impact of contact time on transfer was dependent on transfer direction. From skin-to-fomite, higher estimated means were observed at 5 s contact time, while a 10 s contact time resulted in greater transfer from fomite-to-skin. These differences may be due to an increased adsorption onto the skin—from skin-to-fomite, less contact time provides less opportunity for virus already adsorbed to the skin to transfer to fomites upon contact, while a longer contact time with a contaminated fomite increases the time available for virus to adsorb to the skin. Pitol et al. (2017) observed minimal influence of contact time (10 s to 10 min) when fingers were immersed in virus-containing liquid to model skin-to-liquid transfer events based on adsorbed virus and unadsorbed viruses in the liquid residual on skin. Contrasting results from Pitol et al. (2017) may be due to the different interactions/forces involved based on the surrounding environment (electrostatic, van der Waals and polar) (Boone & Gerba, 2007).

In consideration of the current peer reviewed literature and based on discussions among authors on the most realistic scenarios for transfer events, transfer was evaluated at an inoculum volume of 2 µl. This represents an analogous volume of a respiratory droplet (>100 µm diameter) in comparison with previous transfer studies (Anderson & Boehm, 2021; Ansari et al., 1988, 1991; Lopez et al., 2013; Mbithi et al., 1992) that deposit higher volumes on fomites prior to transfer events. Biryukov et al. (2020) did not observe differences in SARS-CoV-2 inactivation kinetics on fomites based on inoculum volumes of 5, 10, of 50 µl. However, further research is needed to characterize how inoculum volume may impact the transfer of enveloped viruses on skin and various surfaces.

Previous research has observed differences in survival on fomites based on inoculum matrix (Baker et al., 2022; Bangiyev et al., 2021). This led to an investigation of artificial saliva and tripartite matrices for their impact on transfer rates in this study to further elucidate two potential transmission routes through saliva/nasal mucus (Biryukov et al., 2020; Gidari et al., 2021; Matson et al., 2020) and faeces (Cevik et al., 2021; Sattar et al., 2003), respectively. In a study investigating the transfer of human coronavirus (299E, OC43) from nitrile-gloved fingers to stainless steel, plastic, cucumber and apple surfaces, no transfer was observed when viruses in a cell culture media matrix were evaluated, yet OC43 supplemented with 10% w/v faecal material resulted in a transfer rate of 0%, 0.52%, 15.51% and 19.82%, for plastic, stainless steel, apple and cucumber surfaces, respectively (Dallner et al., 2021). Significant differences in transfer rates based on inoculum matrix were observed in the present study from skin-to-fomite, but not from fomite-to-skin. It is possible that there was less interaction of Φ6 with skin in artificial saliva in comparison with tripartite matrix, which may have more strongly attached to the skin and thus resulted in less transfer from skin-to-fomite. The current study provides Φ6 transfer data on four different fomites (touchscreen, vinyl, aluminium and unpainted wood) from those that were previously reported on by Anderson and Boehm (2021) including stainless steel, plastic and painted wood. The lowest transfer rates were observed among untreated wood in this study.

Zhao and Li (2019) developed a sequential touch surface method to avoid common issues of surface sampling such as large standard deviations among trials. In Study 3 (*sequential transfer to surface-to-skin*) of the current research, significant differences were observed in the number of sequential transfer events observed from fomite-to-skin for plastic, touchscreen and vinyl, which further supports data from the previous studies in that surface type impacts transfer rates. Artificial saliva was investigated in Study 3 based on minimal differences

observed among inoculum matrix in Study 2. Similarly, 10 s was investigated based on higher transfer observed in Study 2. Wood was excluded due to low transfer observed in Study 2 and metal surfaces (aluminium and stainless steel) were excluded due to similar results observed in Study 2 and to investigate less commonly assessed surfaces (vinyl, aluminium and touchscreen). Moreover, the current study helps identify which surfaces can potentially lead to a higher number of transfer events following surface contamination.

Although there is potential for SARS-CoV-2 transmission via fomites (Günther et al., 2020; Liu et al., 2020; Xie et al., 2020), an overall low risk of indirect transmission via fomites has been postulated (Baker & Gibson, 2022; Butot et al., 2022; Kumar et al., 2021; Onakpoya et al., 2021; Pitol & Julian, 2021; Wilson et al., 2021; Woodcock, 2021). Future transfer experiments should evaluate how environmental factors impact transfer, specifically surface temperature based on the prolonged virus survival at lower temperatures relevant to seasonal fluctuations and various indoor environments (e.g. food manufacturing facilities) (Chi et al., 2021). For example, the current study was performed at ca. 22°C, which is unlikely to represent the interaction between skin and fomites subjected to colder conditions. Discerning how contact time, inoculum matrix, surface type and other factors impact transfer rates will better inform risk assessments for SARS-CoV-2 as well as emerging enveloped viruses of public health importance. The data from the current study highlight the various factors that can impact Φ6 transfer between skin and fomites, which should be considered for risk assessments focused on virus transmission in consumer-facing environments.

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CONFLICT OF INTEREST

No conflict of interest declared.

DISCLAIMER

This document has not been formally reviewed by the U.S. Food and Drug Administration and should not be construed to represent Agency determination or policy.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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