Abstract: In light of the close contact between patient and clinician during ophthalmic examinations and the multiple opportunities for pathogen transmission, we identified and evaluated potential pathogen transmission routes through high-touch surfaces in an outpatient ophthalmology clinic. A circuit simulation was performed to replicate a patient’s journey through an ophthalmology clinic with various stations. Fluorescent oil and powder were applied to the hands of Simulated Patient A who went through the circuit. Routine disinfection of surfaces in the slit lamp environment and hand hygiene by the ophthalmologist were conducted prior to Simulated Patient B going through the same circuit with untagged hands. Ultraviolet black light was used to identify fluorescent marker contamination after Simulated Patient B completed the circuit. Fluorescent marker contamination was found on the hands of all the simulated patients and staff, various items of the simulated patients, multiple equipment surfaces—particularly the ophthalmologist’s working table and slit lamp environment—and miscellaneous objects like appointment cards and files. Fluorescent marker contamination on Simulated Patient B’s untagged hands despite proper hand hygiene being performed prior suggests suboptimal surface disinfection following Simulated Patient A’s circuit. Through this pilot study, we recognised the key role that ophthalmic high-touch surfaces play in fomite transmission and that thorough disinfection of high-touch surfaces is essential on top of proper hand hygiene. With the contact sequences delineated in this pilot study, specific cues for hand hygiene and surface disinfection may be implemented at suitable intervals during contact with high-touch surfaces. Environmental decontamination adjuncts could also be considered to reinforce surface disinfection.

Keywords: high-touch surfaces; ophthalmic environment; hand hygiene; hospital cleaning and disinfection; ultraviolet markers

1. Introduction

Infection control is important in medical practice to prevent healthcare-associated infections. This is especially so in ophthalmic practices, where close clinician–patient contact is routine, and many surfaces on ophthalmic equipment are susceptible to contamination by pathogens arising from one’s skin and mucosal surfaces. To counteract this, many tiers of infection control exist, from a personal to systemic level, in the form of personal hygiene, sterilisation of equipment, infection screens and design and engineering elements of hospital facilities [1]. However, infection control practices are still fallible and pathogens may spread through multiple modes of transmission, including fomite transmission.

In the ophthalmic setting, fomites can arise from multiple sources. Respiratory droplets and aerosols generated during verbal communication, sneezing, or coughing may contami-
nate equipment surfaces. During a slit lamp examination, patients are in close proximity to the ophthalmologist and have parts of their face resting on the forehead rest and chin-rest. Should they cough, sneeze, or communicate with the ophthalmologist whilst in this position, respiratory droplets are released, contaminating the slit lamp surface with a consequent risk of droplet transmission to the clinician. While this may be mitigated through mask-wearing, Leung et al. observed that mask-wearing did not significantly reduce influenza virus detection in aerosols, suggesting that aerosolisation of viral particles persists despite mask-wearing [2]. Furthermore, another study found that respiratory droplets can gather on side bars adjacent to the slit lamp chin-rest even with the wearing of surgical masks, circumventing mask-wearing measures when it comes to the spread of infection [3].

Skin contact with ophthalmic surfaces can also result in transfer of skin commensals and unknown pathogens. Researchers have isolated bacterial species of normal skin flora from contact surfaces on ophthalmic equipment (grip areas of lenses, slit lamps, ophthalmoscopy helmets, ultrasound probes); coagulase-negative staphylococci was most commonly isolated, followed by *Micrococcus* spp. [4]. Pathogen transmission through skin contact with ophthalmic surfaces is especially significant with mask-wearing in the current healthcare setting. Patients or healthcare workers may contaminate both their hands and other surfaces they come into contact with after touching the outer surface of their masks—a site where severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been found to persist for up to 7 days [5].

Several viruses have also been detected in ocular secretions: adenovirus 8, human immunodeficiency virus, herpes simplex virus-1 and hepatitis B [6–9]. Such secretions may contaminate surfaces, leading to pathogen transmission through fomites. The above methods of pathogen transmission indicate that infection control via strict hand hygiene and routine thorough environmental cleaning should not be neglected.

Delineating specific surfaces at increased risk of contamination and possible transmission routes is essential in devising strategies for containment. Several high-risk and high-touch surfaces involving ophthalmic equipment have been previously identified: Goldmann applanation tonometer prism tips, slit lamps, chin-rests and table surfaces of ophthalmic investigative equipment like automated visual field analysers and optical coherence tomography machines [10]. One investigation identified specific high-touch surfaces in the ophthalmic slit lamp environment which were persistently contaminated, thereby demonstrating the inefficacy of existing cleaning practices, especially for irregular surfaces such as the ridged knobs of the slit lamp [11]. Additionally, *Staphylococcus aureus* was isolated from high-touch ophthalmology clinic surfaces, including door knobs, slit lamp headrests and chin-rests and computer keyboards [12]. These are potential sites of pathogen contamination. One study used non-microbial plant DNA markers to model the spread of pathogens between surfaces in a neonatal intensive care unit and found that the marker spread rapidly between hospital environmental surfaces and staff’s hands [13]. This highlights the role that high-touch surfaces play in cross-contamination, thus reinforcing the need for routine environmental cleaning.

At present, a study has identified the two most common touch sequences by hospital staff in the ward setting: touching the patient followed by the bedrail and vice versa and touching the computer terminals followed by the patient and vice versa [14]. While extensive research has been conducted to identify lists of high-touch surfaces, the aforementioned study highlights the value in the identification of interconnection between individuals and objects in the clinical setting via touch sequences. This uncovers the routine touch sequences of healthcare workers which they may lack awareness of and presents specific opportunities to introduce interventions that can help improve environmental hygiene as a part of the healthcare workers’ routine, in addition to the World Health Organisation’s (WHO) “Five Moments for Hand Hygiene”.

Close contact between patients and healthcare workers and the multiple opportunities for pathogen transmission in ophthalmology clinics make the identification of ophthalmic
high-touch surfaces and potential transmission routes through such surfaces salient. Using fluorescent oil and powder as a visual surrogate marker, this pilot study aims to identify the possible routes of fomite transmission in an outpatient ophthalmology clinic.

2. Materials and Methods

2.1. Phase I—Circuit Simulation

This experiment simulated a patient’s journey through an ophthalmology clinic. Performed in accordance with the Declaration of Helsinki, institutional review board approval was not required for this investigation. Hands of involved personnel and different areas in the circuit were cleaned following established disinfection protocols. Involved personnel’s hands were disinfected using 4% w/v chlorhexidine gluconate solution (Microshield 4 Chlorhexidine Surgical Handwash, Schülke, Germany), while surfaces in the ophthalmology clinic were wiped down using 70% isopropyl alcohol wipes (HospiCare 701, Freshening Industries Pte Ltd., Singapore). Individuals’ hands and different surfaces were assessed using ultraviolet (UV) black light (Glo Germ Company, Moab, UT, USA) to ensure null contamination. Thereafter, fluorescent powder and oil (Glo Germ Company, Moab, UT, USA) were applied to the hands of a simulated patient—Patient A. The disinfection practices were demonstrated to effectively eliminate the fluorescent powder and oil from the hands and various clinic surfaces prior to the start of the circuit. Patient A registered and was attended to as per a regular ophthalmic consultation by the various healthcare workers. The stations in the circuit included registration, visual acuity screening, consultation with slit lamp (Haag-Streit BM900, Haag-Streit AG, Köniz, Switzerland) examination and payment. Table 1 outlines the chronology of the circuit.

<table>
<thead>
<tr>
<th>Station</th>
<th>Action Sequence</th>
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| Registration      | 1. Patient A passes the appointment card to the registration staff.  
2. Registration staff takes the appointment card, then hands the card, an appointment file and an appointment number slip to Patient A. |
| Visual Acuity Station | 1. Patient A walks to the visual acuity station and passes the appointment file to the visual acuity station technician.  
2. The technician hands a Lorgnette pinhole occluder to Patient A.  
3. Patient A holds the Lorgnette pinhole occluder to the eyes and is assessed.  
4. The technician uses a remote control to switch between different Snellen charts.  
5. The technician takes the occluder back from Patient A without cleaning, uses the computer keyboard to type the findings and hands the appointment file back to Patient A. |
| Consultation Room | 1. Patient A slides the appointment file into a slot outside the consultation room and sits in the waiting area.  
2. Consultation room clinical assistant picks up the file and gives the file to the ophthalmologist, before calling for Patient A to enter the consultation room.  
3. The ophthalmologist uses a handheld scanner to scan a barcode on the documents in the file.  
4. The ophthalmologist positions Patient A for a slit lamp examination—chin on the chin-rest, forehead against the forehead rest and hands holding the handlebars.  
5. The ophthalmologist conducts a slit lamp examination on Patient A.  
6. The ophthalmologist uses the computer mouse and keyboard to type the relevant notes.  
7. The ophthalmologist returns the appointment file and card to the patient.  
8. Items such as the printer, work telephone and alcohol rub were used when necessary. |
| Payment           | 1. Patient A returns the appointment file to the payment counter staff.  
2. Payment counter staff hands the appointment card back to Patient A. |

After Patient A’s circuit, the ophthalmologist’s hands were washed using 4% w/v chlorhexidine gluconate solution (Microshield 4 Chlorhexidine Surgical Handwash, Schülke, Germany), and routine wipedown of surfaces in the slit lamp environment using 70% isopropyl alcohol wipes (HospiCare 701, Freshening Industries Pte Ltd., Singapore) was conducted. Following routine disinfection practices, a second simulated patient (Patient
B), whose hands were not tagged with fluorescent powder and oil, followed through with the exact same circuit as described in Table 1. After Patient B completed his circuit simulation, no further handwashing nor cleaning were carried out, and an evaluation of surface contamination was performed. The simulation sequence was conducted once with no further repeats.

2.2. Phase II—Evaluating Surface Contamination and Transmission

At the end of the circuit simulation, UV black light was used to illuminate the station environment. Contaminated areas surfaces which fluoresced under the UV black light were documented through photographs. Besides surveying the clinic for areas of fluorescence, the hands, clothing and various belongings and items (including masks) of healthcare workers were also reviewed to identify contamination. Similarly, photographs of the contaminated areas on the healthcare workers were taken.

3. Results

Figure 1 illustrates the ophthalmologist’s work table in the consultation room which was used in the simulation. The main surfaces in the ophthalmologist’s work area which fluoresced under UV black light are marked out in the illustration in pink.

![Figure 1. Ophthalmologist’s work table in consultation room with fluorescent areas marked out in pink.](image-url)

Table 2 shows a detailed list of the identified surfaces with areas of fluorescence throughout the entire circuit, as well as the individuals whose hands and clothing showed fluorescence. Selected images of the corresponding surfaces and hands are also depicted in Figure 2.

|------------------------------------------|------------|------------|---------------------|--------------------------------------|----------------|--------------------------------|-------------------------|

Table 2. List of surfaces that fluoresced under ultraviolet black light.
Table 2. Cont.

<table>
<thead>
<tr>
<th>Contaminated surfaces in the consultation room</th>
<th>7. Base of the sink (near the sink drain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Surface of ophthalmologist’s working table</td>
<td>8. Water tap handle</td>
</tr>
<tr>
<td>2. Keyboard</td>
<td>9. Patient chair height adjustment lever</td>
</tr>
<tr>
<td>4. Consultation room door and door handle</td>
<td>11. Eye drop bottles</td>
</tr>
<tr>
<td>5. Backrest of patient’s chair in consultation room</td>
<td>12. Work telephone</td>
</tr>
<tr>
<td>6. Edge of sink basin</td>
<td>13. Alcohol rub</td>
</tr>
<tr>
<td></td>
<td>14. Printer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contaminated surfaces at the visual acuity station</th>
<th>3. Remote control</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Lorgnette pinhole occluder: eyepiece and handle</td>
<td>5. Computer table surface</td>
</tr>
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<thead>
<tr>
<th>Contaminated surfaces on the slit lamp</th>
<th>9. Eyepiece</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Posterior surface of forehead rest contacted by patients</td>
<td>10. Sliding base of slit lamp</td>
</tr>
<tr>
<td>2. Top surface of chin-rest contacted by patients</td>
<td>11. Brightness control knob</td>
</tr>
<tr>
<td>3. Handlebars</td>
<td>12. Power supply box</td>
</tr>
<tr>
<td>4. Slit lamp rail cover</td>
<td>13. Table height adjustment lever</td>
</tr>
<tr>
<td>5. Chin-rest adjustment knob</td>
<td>14. Slit lamp table surface (top and side)</td>
</tr>
<tr>
<td>6. Slit lamp vertical rods</td>
<td>15. Inferior surface of slit lamp table (next to table height adjustment lever)</td>
</tr>
<tr>
<td>7. Joystick</td>
<td>16. Trash bag attached to the slit lamp table</td>
</tr>
<tr>
<td>8. Breath shield</td>
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</table>

<table>
<thead>
<tr>
<th>Miscellaneous</th>
<th>1. Appointment card and file</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2. Backrest of waiting area chair</td>
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</table>

<table>
<thead>
<tr>
<th>Miscellaneous</th>
<th>3. Registration staff’s pen</th>
</tr>
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Figure 2. Images of surfaces and hands fluorescing under ultraviolet black light: (a) Patient A’s hands, (b) Patient B’s hands, (c) Patient B’s surgical mask, (d) Patient A’s shirt, (e) computer mouse and surface of ophthalmologist’s working table in consultation room, (f) consultation room door handle, (g) remote control and Lorgnette pinhole occluder at visual acuity station, (h) keyboard at visual acuity station, (i) slit lamp and patient chair in consultation room, (j) joystick of slit lamp, (k) appointment files and (l) backrest of waiting area chair.

4. Discussion

4.1. Contact Sequences and Possible Routes of UV Fluorescent Marker Transmission

Figures 3–5 outline contact sequences of surfaces between the different individuals. A double arrowhead suggests a two-way contact sequence where the item was received.
and passed to a different individual, while a single arrowhead suggests a one-way contact sequence where the item was simply touched by the individual.

Figure 3. Contact sequences at the registration, visual acuity and payment stations.

Figure 4. Contact sequences in the consultation room.

Figure 5. Contact sequences in Patient B’s circuit that resulted in the contamination of the ophthalmologist’s and Patient B’s hands.

As evident from Figures 3 and 4, a significant fomite is the appointment file which was handled by all individuals involved in the circuit as an item of continuity throughout the consult process. The appointment card and file were similarly implicated in cross-contamination as these items were handled by the patient, registration staff and payment counter staff, while the Lorgnette pinhole occluder was handled by the patient and visual
acuity station technician. During the consultation, cross-contamination between Patient A and the ophthalmologist occurred via two routes—both individuals touching the same surface on the slit lamp table and the practice of handshaking. The ophthalmologist subsequently proceeded to touch a number of other surfaces, as seen in Figure 4.

After Patient A’s circuit, the ophthalmologist practiced hand hygiene at the sink, resulting in contamination of the faucet. The side edges of the sink basin also contained areas of fluorescence, likely due to splashback from washing, and may not be representative of contamination from direct contact.

Despite handwashing, the ophthalmologist’s and Patient B’s hands were found to be contaminated at the end of Patient B’s circuit despite a lack of initial application of fluorescent markers to Patient B’s hands. This suggests suboptimal disinfection of contaminated surfaces from Patient A’s circuit prior to the start of Patient B’s circuit. The residual contamination on multiple surfaces from Patient A’s circuit (as listed in Figure 5) resulted in the ophthalmologist and Patient B contaminating their hands during Patient B’s circuit. Thus, good hand hygiene alone appears to be insufficient, and thorough disinfection of high-touch surfaces should be performed in conjunction to prevent cross-contamination between various individuals. Lei et al. proposed a quantitative hygiene criterion which delineated the frequency of hand hygiene and surface disinfection that was required to stop fomite transmission in indoor environments—the product of pathogen-removal rates on hands and surfaces (including hand hygiene, surface disinfection and natural death of pathogens) must be equal to or greater than that of human hand and surface contact frequency [15]. Therefore, it is paramount that frequent surface disinfection and effective hand hygiene complement each other to halt the effects of fomite transmission, especially in a busy ophthalmic clinic where human hand and surface contact frequency will be high.

Contamination was also identified on both patients, including the outer surface of surgical masks, clothing and Patient A’s spectacles. Kwok et al. conducted a behavioural observation study on the face-touching frequency of medical students during a university lecture, establishing an average of 23 facial touches per hour among 26 students, with 44% of facial contact involving a mucosal membrane [16]. Subconscious behaviour such as face-touching and adjusting one’s mask and clothing can potentially result in self-inoculation of pathogens acquired from high-touch surfaces. The close proximity of the surgical mask and spectacles to mucosal membranes such as the eyelids, mouth and nose is significant as a potential portal of entry into the hosts.

Mutual-touch surfaces (e.g., patient’s appointment file) contributed to a significant proportion of contamination. Simultaneously, contamination found on areas of subconscious contact indicate how habitual behaviour as innocuous as resting one’s hand on the table could prime the same surface for transmission. In the consultation room, surfaces contacted by patients (e.g., chin-rest) and the ophthalmologist (e.g., eyepiece of slit lamp) revealed contamination. In particular, irregular and grooved surfaces contacted by the ophthalmologist to adjust the slit lamp to the patient’s position before the actual examination retained residual contamination as well. This is in concordance to a study conducted by Boyce et al. which used an adenosine triphosphate bioluminescence assay for assessing the efficacy of daily cleaning practices in 20 patient rooms—smooth, flat surfaces were found to be cleaned more effectively than irregular surfaces [17]. This highlights the need for existing disinfection practices to be more focused on targeting these irregular surfaces. Finally, contamination present on the untagged hands of Patient B and all other healthcare workers involved in the circuit poses a sobering reminder on the ease of widespread pathogen transmission between individuals via high-touch surfaces, underscoring the need for stringent adherence to both proper hand hygiene and optimal disinfection practices.

4.2. Hand Hygiene and Disinfection of Ophthalmic Equipment

To tackle pathogen transmission, good hand hygiene in conjunction with effective disinfection of surfaces are of paramount importance. Yet, hand hygiene practices in healthcare institutions are not completely adhered to. An observational study measuring
the hand hygiene compliance of healthcare workers, patients and visitors in diabetic care and respiratory medicine wards demonstrated an overall compliance rate of 67.8%. Out of the hand hygiene opportunities made available to healthcare workers based on the WHO’s “Five Moments for Hand Hygiene”, the reported compliance rates for healthcare workers ranged from 47% to 78% [18]. Of note, hand hygiene compliance following contact with a patient’s surroundings is generally lower than that following direct patient contact [19]. As our study has revealed, practising hand hygiene after interacting with the patient’s surroundings is as important as after touching the patient, given that surrounding surfaces can serve as fomites for pathogen transmission.

As ophthalmic equipment are in either close or direct contact with patients, these serve as routes of pathogen transmission. Examples of ophthalmic equipment that require cleaning after an ophthalmic examination include the slit lamp and the Goldmann applanation tonometers used during slit lamp examination. Additionally, the slit lamp examination table and its various controls such as the power supply box, brightness control knob and the table height adjustment lever should also be sterilised. The Lorgnette pinholer should also be cleaned after visual acuity testing. Recommendations for cleaning of ophthalmic equipment may generally include alcohol wipes, alcohol or sodium hypochlorite-containing solutions [20]. Specifically, Junk et al. analysed 10 laboratory studies investigating the efficacy of different disinfectants for reusable applanation tonometers and recommended elimination of adenovirus to be achieved by using 1:10 dilute bleach, as two out of four studies have found 70% isopropyl alcohol and 3% hydrogen peroxide to be ineffective in eliminating this pathogen [21]. During the coronavirus disease 2019 (COVID-19) pandemic, the American Academy of Ophthalmology listed several disinfectant agents for SARS-CoV-2 based on the Centers for Disease Control and Prevention’s (CDC) recommendations, including solutions with at least 70% alcohol [22]. Human coronaviruses on surfaces were also found to be inactivated by one minute of exposure to 62–71% ethanol, 0.5% hydrogen peroxide or 0.1% sodium hypochlorite [23]. A study has shown that frequent disinfection of high-touch surfaces can reduce the acquisition of pathogens—such as methicillin-resistant Staphylococcus aureus (MRSA) and Clostridium difficile—on the hands of healthcare workers [24]. Hence, sterilisation of equipment should be immediately carried out in between ophthalmic examinations [25].

Good hand hygiene may be achieved via hand sanitisers containing 60 to 95% alcohol, as recommended by the CDC. Alcohol has demonstrated excellent in vitro germicidal activity against Gram-positive and Gram-negative vegetative bacteria and also against enveloped lipophilic viruses like herpes simplex virus and influenza virus [26]. During the COVID-19 pandemic, 70% ethanol was found to inactivate SARS-CoV-2 to undetectable levels in suspension testing—an important preventive measure against cross-infection [27]. One study proposed the provision of cues to healthcare workers to identify the need for hand hygiene by providing opportunities for disinfection of their hands. For example, by the positioning of alcohol-based hand rubs en route to a task where hand hygiene is required, healthcare workers are reminded of the need for hand hygiene at that point in time with a visual cue [28]. All of the above may be undertaken in conjunction to reduce pathogen transmission through high-touch surfaces.

In addition to conscientious hand hygiene practices and effective disinfection of surfaces, environmental decontamination adjuncts could also be considered. Marchesi et al. reported efficacy of dry steam in reducing human coronavirus OC43, human influenza virus A/H1N1/WSN/33 and echovirus 7 titres on various surfaces—stainless steel, polyethylene and cotton surfaces [29]. Schneider et al. discussed the emergence of environmental surface disinfection as part of preventing hospital-acquired infections (HAIIs), especially with no-touch automated disinfection systems having been shown to decrease environmental microorganism levels [30]. Examples of such systems include hydrogen peroxide vapour or mist and UV radiation. However, Dancer and King caution against the use of automated disinfection systems. The efficacy of environmental sanitation systems in reducing infection rates of various pathogens like C. difficile, vancomycin-resistant enterococcus and MRSA
can be largely variable—as evidenced by Dancer and King’s systematic review, which evaluated the effect of automated technologies delivering hydrogen peroxide and UV light on HAI rates. While Dancer and King recognise that mixed results could be explained by various confounders across the studies, they advise against the over-reliance on modern technology to control hospital-acquired infection rates due to the significant amount of resources required to maintain such automated systems. This is coupled with potential toxicity carried by chemicals, as well as bacterial mutations that could be caused by UV light [31]. Therefore, while modern technologies carry great potential in enhancing existing infection control practices as adjuncts, the pros and cons of installing such devices should be weighed and these devices should not serve as a replacement to current hand hygiene and manual housekeeping practices.

4.3. Limitations

The simulated patients recruited were clinicians working at the ophthalmology clinic. This may have introduced selection bias as the patient’s interaction with the ophthalmic environmental surfaces could be misrepresented. However, given their experience with patients on a regular basis, it is conceivable that their representation of patients within the circuit was reasonably accurate. Of note, the circuit simulation was conducted once and not repeated with involvement of other simulated patients and a wider range of healthcare workers. Further studies involving more patients and a wider range of healthcare staff within the patient journey would be useful to corroborate information identified in this pilot study. Another limitation stems from the use of fluorescent markers to represent contamination in the circuit, where these markers represented a surrogate for the transmission of pathogens. The existing literature has established that contaminated environmental surfaces contribute to hospital-associated pathogen transmission, and this approach fulfilled the study’s objective to chart specific high-touch surfaces where pathogens can reside and spread in the ophthalmology clinic to facilitate the improvement of infection prevention protocols [32]. It serves to highlight the gaps in current cleaning practices as well. Lastly, this study focuses on fomite transmission in an ophthalmology clinic using fluorescent markers but does not represent other possible modes of transmission. For example, respiratory viruses like SARS-CoV-2 can be transmitted by aerosols and droplets but due to the limitation of using fluorescent oil and powder to tag the aerosols and droplets produced by patients, the investigation of droplet and airborne transmission was deliberately omitted from this study [33]. Moreover, the appointment file was the sole item of continuity in this study and did not include possibilities whereby patients may travel with relatives and other belongings as additional factors of transmission.

5. Conclusions

The results obtained from this pilot study provide evidence that ophthalmic high-touch surfaces are potential routes for pathogen transmission and that current cleaning practices need to be more robust. It is imperative that stringent infection control measures like equipment cleaning and hand hygiene are optimised to prevent pathogen transmission. This pilot study may also serve as a springboard for further research on high-touch surface transmissions in other settings outside of ophthalmology as well.

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