

Protecting healthcare workers during the COVID-19 pandemic with new technologies: acceptability, feasibility and impact of the HoloLens2™ mixed reality headset across multiple clinical settings

Guy Martin, Louis Koizia, Angad Kooner, John Cafferkey, Clare Ross, Sanjay Purkayastha, Arun Sivananthan, Anisha Tanna, Philip Pratt, James Kinross, PanSurg Collaborative

Submitted to: Journal of Medical Internet Research
on: June 16, 2020

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript	4
Supplementary Files	24
Figures	25
Figure 1.....	26
Figure 2.....	27
Multimedia Appendixes	28
Multimedia Appendix 1.....	29

Ahead of Print
JMIR Publications



Protecting healthcare workers during the COVID-19 pandemic with new technologies: acceptability, feasibility and impact of the HoloLens2™ mixed reality headset across multiple clinical settings

Guy Martin, Louis Koizia, Angad Kooner, John Cafferkey, Clare Ross, Sanjay Purkayastha, Arun Sivananthan, Anisha Tanna, Philip Pratt, James Kinross, PanSurg Collaborative

Corresponding Author:

Guy Martin

Phone: +447944572999

Email: guy.martin@imperial.ac.uk

Abstract

Background: The COVID-19 pandemic has led to rapid acceleration in the deployment of new digital technologies to improve both accessibility and quality of care, and to protect staff.

Objective: This pilot project sought to deploy the HoloLens2™ mixed reality (MR) device to support the delivery of remote care in COVID-19 hospital environments.

Methods: A prospective observational nested cohort evaluation of the HoloLens2™ was undertaken across three distinct clinical clusters in a UK teaching hospital. Data pertaining to staff exposure to high-risk COVID-19 environments and PPE use were collected, and assessments of acceptability and feasibility conducted.

Results: The deployment of HoloLens2™ led to a 51.5% reduction in time exposed to harm for staff looking after COVID-19 patients (3.32 vs. 1.63 hours/day/staff member, $p=0.002$), and a 83.1% reduction in the amount of PPE used (178 vs. 30 items/round/day, $p=0.017$). This represents 222.98hrs reduced staff exposure to COVID-19, and 3,100 fewer items of PPE used each week across the three clusters evaluated. The majority of staff using the device agreed it was easy to set up and comfortable to wear, improved the quality of care and decision making, and led to better teamwork and communication. 89.3% of users felt that their clinical team was safer when using the HoloLens2™.

Conclusions: New technologies have a role in minimising exposure to nosocomial infection, optimising the use of PPE and enhancing aspects of care. Deploying such technologies at pace requires context specific information security, infection control, and user experience and workflow integration to be addressed at the outset and led by the clinical end-users. The deployment of new telemedicine technology must be supported with objective evidence for its safety and effectiveness to ensure maximum impact.

(JMIR Preprints 16/06/2020:21486)

DOI: <https://doi.org/10.2196/preprints.21486>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

Please make my preprint PDF available to anyone at any time (recommended).

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

✓ **No, I do not wish to publish my submitted manuscript as a preprint.**

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?


✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible to all users.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in [http](#)

Original Manuscript

Ahead of Print
JMIR Publications

The logo for JMIR Publications, featuring a stylized network of three nodes connected by lines, enclosed in a circle.

ORIGINAL PAPER

Protecting healthcare workers during the COVID-19 pandemic with new technologies: acceptability, feasibility and impact of the HoloLens2 mixed reality headset across multiple clinical settings

Guy Martin^{1,2}, Louis Koizia³, Angad Kooner⁴, John Cafferkey⁴, Clare Ross⁴, Sanjay Purkayastha^{1,2}, Arun Sivananthan¹, Anisha Tanna⁵, Philip Pratt⁶, James Kinross^{1,2} on behalf of the PanSurg Collaborative¹

¹ - Department of Surgery and Cancer, Imperial College London, London, UK

² - Division of Surgery, Imperial College Healthcare NHS Trust, London, UK

³ - Cutrale Perioperative and Ageing Group, Imperial College London, London, UK

⁴ - Division of Medicine, Imperial College Healthcare NHS Trust, London, UK

⁵ - West London Renal and Transplant Centre, Imperial College Healthcare NHS Trust, London, UK

⁶ - The Helix Centre, Imperial College London, London, UK

Corresponding Author:

Guy Martin

Department of Surgery and Cancer

Imperial College London

10th Floor QEQM Building, St Mary's Hospital, London, W2 1NY

guy.martin@imperial.ac.uk / +447944 572999

Keywords:

Covid-19, mixed reality, telemedicine

ABSTRACT

Background:

The COVID-19 pandemic has led to rapid acceleration in the deployment of new digital technologies to improve both accessibility and quality of care, and to protect staff. Mixed reality technology is the latest iteration of telemedicine innovation and is logical next step in the move towards the provision of digitally supported clinical care and medical education. The technology has the potential to revolutionise care both during and after the COVID-19 pandemic.

Objective:

This pilot project sought to deploy the HoloLens2 mixed reality (MR) device to support the delivery of remote care in COVID-19 hospital environments.

Methods:

A prospective observational nested cohort evaluation of the HoloLens2 was undertaken across three distinct clinical clusters in a UK teaching hospital. Data pertaining to staff exposure to high-risk COVID-19 environments and PPE use were collected, and assessments of acceptability and feasibility conducted.

Results:

The deployment of HoloLens2 led to a 51.5% reduction in time exposed to harm for staff looking after COVID-19 patients (3.32 vs. 1.63 hours/day/staff member, $p=0.002$), and a 83.1% reduction in the amount of PPE used (178 vs. 30 items/round/day, $p=0.017$). This represents 222.98hrs reduced staff exposure to COVID-19, and 3,100 fewer items of PPE used each week across the three clusters evaluated. The majority of staff using the device agreed it was easy to set up and comfortable to wear, improved the quality of care and decision making, and led to better teamwork and communication. 89.3% of users felt that their clinical team was safer when using the HoloLens2.

Conclusions:

New technologies have a role in minimising exposure to nosocomial infection, optimising the use of PPE and enhancing aspects of care. Deploying such technologies at pace requires context specific

information security, infection control, and user experience and workflow integration to be addressed at the outset and led by the clinical end-users. The deployment of new telemedicine technology must be supported with objective evidence for its safety and effectiveness to ensure maximum impact.



Introduction

The COVID-19 pandemic has overwhelmed even the most developed and well-resourced health systems[1]. Difficult decisions regarding the rationing of personal protective equipment (PPE) for healthcare workers and even access to care for patients have had to be made[2]. Protecting the health and safety of care workers is a key priority to maintain the quality of care delivered to individual patients and the ability of health systems to deliver care at scale[3]. In Italy up to 20% of healthcare workers have become infected with the virus[4], and in the UK over 15% of positive tests have been in critical healthcare workers[5] and over 100 have died[6]; a picture that has been seen globally. A key aspect of this has been severe disruption and shortages in the global supply of PPE due to excess demands and misuse[7]. As such, novel methods that optimise PPE use and protect both healthcare workers and patients from COVID-19 transmission are urgently required[8].

Digital innovation has been identified as key to tackling the challenge to staff safety that COVID-19 confers[9]. The pandemic has rapidly accelerated the deployment of new technologies such as telemedicine services[10]. Telemedicine provides a means to deliver care efficiently and leverage access to multiple remote specialists while simultaneously protecting staff and patients from exposure to the virus[11,12]. Mixed reality (MR) technology offers an immersive experience in which real and virtual elements of an environment dynamically co-exist; it is the most recent iteration and extension of telemedicine innovation with the potential to revolutionise clinical care and education through the provision of enhanced functionality and novel content. The HoloLens2 is an untethered wearable holographic computer that allows bidirectional communication with multiple remote users via video, voice and MR composites. The technology has been used previously in a variety of clinical and educational scenarios including perioperative planning, surgical training, anatomical teaching and 3D telemedicine support[13–17]. The technology offers the potential to increase user immersion and engagement, supplement situational awareness and access to knowledge in real-time and improve performance. It allows users to interact and manipulate spatially registered 3D holographic content within a real environment, and to remotely link with multiple devices and users to allow simultaneous collaborative interaction and working within the visualised environment. MR technology is in its infancy, but is the logical next step in the move towards the provision of digitally supported clinical care and education.

The HoloLens2 device has not previously been deployed for the delivery of ward-based secondary care in high-risk environments. This technology-led pilot therefore deployed and evaluated the

HoloLens2 for the delivery of remote care across a range of inpatient settings in a UK teaching hospital during the COVID-19 pandemic response. The aim was to assess the practicalities and impact of deploying MR telemedicine technologies for improving staff safety during the time of COVID-19.

Methods

Conduct:

The objective of this project was to assess the practicalities and clinical impact of introducing a remote distributed care model supported by HoloLens2. All technology sits within a multi-domain system that includes its users and environment; it cannot be developed, deployed or evaluated in isolation[18]. Workflow considerations and human factors must therefore also be considered alongside technical decisions when understanding the practicalities and impact of implementing a digital technology and models of care at pace.

A prospective observational nested cohort evaluation of the HoloLens2 as a technology-led Quality Improvement (QI) project was performed. The device was deployed and evaluated across three distinct clinical clusters: a COVID-19 general medicine ward, a specialist COVID-19 unit providing continuous positive airway pressure (CPAP) support, and finally a specialist unit providing care to COVID-19 patients with renal disease. High-level aggregate outcome data pertaining to staff exposure to high-risk COVID-19 environments and PPE use were collected. Assessments of feasibility and acceptability were undertaken via user experience questionnaires with Likert and free-text responses. Local institutional registration and approval was obtained, and data governance and infection prevention and control procedures agreed prior to commencement of the project. No additional ethical approval was required as the project was conducted as a technology-led quality improvement project under supervision of the institutional Quality Improvement Team. Explanatory information was provided to all participants. All data was arranged, structured and analysed in Microsoft Excel (Excel for Mac V15.22, Microsoft Corporation, USA) and IBM SPSS (SPSS for Mac V26, IBM Corporation, USA). With regards statistical analysis, standard descriptive statistics were employed, and two-tailed students *t*-tests were used to compare differences, with significance at $p < 0.05$.

Role of the Funding Source:

The research was supported by the UK NIHR Biomedical Research Centre based at Imperial College Healthcare NHS Trust and Imperial College London. Microsoft Corporation (Redmond, WA, USA) provided in-kind support through the provision of technical assistance and supply of devices. This paper represents independent research. The funders, and specifically Microsoft Corporation, had no involvement in the study design; data collection, analysis and interpretation; writing of the report; or decision to submit the paper for publication.

Workflow:

Prior to the deployment of HoloLens2, standard clinical practice in all three areas was to provide clinical care through face-to-face ward rounds comprising 3-8 members of clinical staff. This required all to don appropriate PPE and provide care in high-risk environments. For this project clinical teams were provided with standardised training on basic functions of the HoloLens2. Teams were not given specific instructions on how to alter their clinical practice or models of care and were free to use the technology in the optimal way for their local clinical context to support the transition to a remote distributed care model.

In general, following deployment a single senior member of staff would enter the COVID-19 environment to undertake rounds, with the remainder of the team joining virtually from a COVID-19 protected non-clinical remote location. All members of the team then played an active role in clinical assessment and decision making through the bidirectional audio-visual functionality of the device, and specifically the first-person bedside view provided to the remote team members. In addition, relevant imaging and Electronic Health Record (EHR) data was placed directly into the field of vision of the device user, with the aim of improving situational awareness, informing better clinical decision making and further reducing the risk of viral transmission by minimising the need to interact physically with equipment and technology in high-risk areas. In parallel, members of the remote team would document encounters in the EHR, and undertake electronic ordering and prescribing was undertaken in real time. Device use and functionality is illustrated in Figure 1.

HoloLens2:

HoloLens2 is produced and marketed by Microsoft Corporation (Redmond, WA, USA), and is an

untethered mixed reality headset that combines several types of sensors; infra-red time-of-flight depth measurement, high definition cameras, accelerometers and microphones. It provides a true heads-up display functionality with the ability to place interactive 2D and 3D objects, such as medical imaging or EHR data, within a user's visual field. Simultaneously, it provides live bidirectional communication via video and voice with multiple remote users through the Remote Assist application to enable hands-free multidisciplinary telemedicine at the bedside. Microsoft Dynamic 365 Remote Assist utilises the architecture of Microsoft Teams - a unified communication and collaboration platform that combines chat, video meetings, file storage and application integration - that was deployed across the National Health Service (NHS) in England to help providers respond to the COVID-19 pandemic[19]. The deployment of existing well-used and flexible platforms is likely to be beneficial as their technical and security considerations are already understood.



Figure 1 - Images demonstrating use and functionality of the HoloLens2. 1A) View of end-user

in PPE wearing the device. 1B) View of remote clinical team engaging in clinical round from a safe location. 1C) First-person view through the HoloLens2 showing the remote clinical team and relevant imaging placed in the user's field of view as Mixed Reality composites (image generated with staff to ensure protection of patient privacy and data).

Information Security and Governance:

Ensuring appropriate information security and governance is vital when utilising new digital technologies, especially when sensitive patient data may be shared electronically. In the UK, NHSX and other relevant bodies recently updated their guidance around the use of digital technology and sharing of data during COVID-19, recognising that a pragmatic risk-based approach needs to be taken, and that an effective pandemic response will require new ways of working[20]. For the deployment of HoloLens2 and Remote Assist we connected devices to the secure hospital Wi-Fi network; devices were specifically white-listed by MAC address and secured by WPA2 pre-shared key (PSK) authentication. We utilised Mobile Device Management (MDM) to automate deployment, provisioning, policy management, application delivery and updates across all devices. User accounts were protected with the use of strong passwords and Multi-Factor Authentication (MFA). Institutional approval with regard to data protection, confidentiality and information sharing was obtained.

Infection Prevention and Control:

The aim of this project was to protect staff from infection; therefore, ensuring a standardised process for wearing the device with PPE, and for device decontamination was vital. Specific PPE requirements varied according to each clinical setting, local risk assessment and clinical tasks being undertaken. However, all members entering a high-risk environment are required to wear 4-5 distinct items of PPE including gown/apron, gloves, hat, mask/respirator and eye protection. A pragmatic, risk-based approach to wearing and decontaminating the HoloLens2 devices was developed, with a standard method for using the device with different PPE that included the use of surgical caps to protect the device, and customised full-face visors for higher risk areas that had a strip cut-out to ensure that the sensors and cameras on the headset were not obstructed, while ensuring adequate protection for staff. The cleaning process was aligned with that used for the decontamination of reusable items of PPE such as full-face plastic visors. The development of safe ways to wear and decontaminate the devices was conducted in partnership with our organisational

Infection Prevention and Control team prior to commencing the project. An example of donning/doffing and decontamination procedures has been provided in the supplementary information (Appendix 1).

Results:

In total, 52 inpatient beds were included across the three clinical clusters, with an aggregate of 51 days of clinical care evaluated during the project. A total of 28 members of clinical staff (57.1% male, 64.3% <35 years of age) completed assessments of acceptability and feasibility. 20/28 (71.4%) of these had no experience of HoloLens2 prior to the project, and 23/28 (82.1%) had never used video calling or telemedicine software before the COVID pandemic.

Deployment of the HoloLens2 led to a significant reduction in the mean aggregate duration that clinical staff (hours/day/staff member) were exposed to high-risk COVID-19 environments whilst delivering clinical care (3.32hrs vs. 1.63hrs, $t=3.21$, $p=0.002$) as shown in Figure 2A. The total reduction in exposure ranged from 7.15hrs to 15.45hrs per day collectively for each team. This saving represents 222.98hrs per week of reduced staff exposure to COVID-19 infection across the three clinical areas evaluated, equivalent to a 51.5% reduction. The overall reduction in exposure to risk was achieved by reducing the number of staff on each round by 2-6 people, and by greatly reducing the duration of each round. In addition, by allowing the completion of administrative tasks that were previously undertaken following completion of the round in parallel, overall efficiency and post-round workload were also reduced: *“Time was saved by not waiting for other people to change PPE between patients and having to repeat the plan on coming out for bays/side rooms. By the time the ward rounds were complete, the documentation and most of the scans/reviews had been requested.”* (Renal Medicine Consultant).

Deployment of the HoloLens2 also led to a significant reduction in the mean number of PPE items used (items/round/day) whilst delivering clinical care in high-risk COVID-19 environments (178 vs. 30, $t=3.88$, $p=0.017$), as shown in Figure 2B. The total reduction in PPE items used ranged from 100 to 204 per day for each team. This represents a total saving of approximately 3,100 items of PPE per week across the three clinical areas evaluated; equivalent to an 83.1% reduction. Importantly, 25/28 (89.3%) felt that their clinical team was safer when using the HoloLens2 to look after COVID-19 positive patients, no member of staff reported any safety concerns whilst using the device and all respondents were happy to use it again: *“The most important thing is that it is able to protect us from getting infected...”* (Junior Doctor).

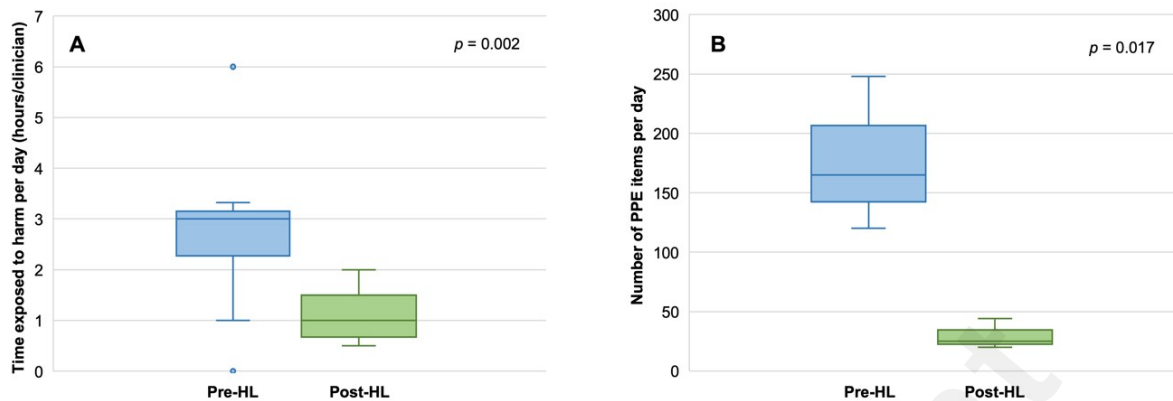


Figure 2 - Aggregate data on staff exposure to risk and PPE use across three clinical areas before and after Hololens2 (HL) deployment. 2A) reduction in time (hours/day/staff member) exposed to high-risk COVID-19 environments (3.32 vs. 1.63 hours, $t=3.21$, $p=0.002$). 2B) reduction in the mean number of PPE items used (178 vs. 30, $t=3.88$, $p=0.017$)

With regards to functionality of the device, 28/28 (100%) of respondents utilised bidirectional audio-visual communication, 23/28 (82.1%) EHR data MR composites, 21/28 (75.0%) imaging MR composites and 16/28 (57.1%) interactive MR tools such as 3D object annotation. Staff found the device easy to use and comfortable to wear; 21/28 (75.0%) agreed the device was easy to set-up and 20/28 (71.4%) that it was comfortable to wear: *“To be honest I forget I am wearing it most of the time”* (General Medicine Consultant). 22/28 (78.6%) of staff agreed that the HoloLens2 led to a quicker round, 21/28 (75.0%) a more efficient round, and 22/28 (78.6%) had a better experience of undertaking care when using the device, with 19/28 (67.9%) feeling more engaged with the round and clinical decision making. 19/28 (67.9%) agreed that the device improved the quality of patient care, and 17/28 (60.7%) that it enabled staff to make better clinical decisions. Only a single respondent (3.6%) reported that it reduced the quality of care, and 2/28 (7.2%) that it did not help support better decision making. 20/28 (71.4%) agreed that it improved the quality of communication within the clinical teams, 23/28 (82.1%) that is improved teamwork and 19/28 (67.9%) that it improved clinical situational awareness for staff whilst reviewing patients: *“You can really see a clear picture so we can fully see all the signs, which on a crowded ward round you may not when you are stuck at the back somewhere”* (Junior Doctor). Overall 21/28 (75.0%) of respondents could see the clear benefit in using the technology and 15/28 (53.6%) of respondents agreed that it should be used for all ward rounds.

Discussion:

Principal Results

This technology-led pilot project has demonstrated that wearable MR devices may have a role to play in protecting staff and reducing PPE use during a pandemic response. The use of HoloLens2 led to an 83.1% reduction in PPE use and a 51.5% reduction in the time spent by clinical staff in high-risk areas. Nearly 90% of staff felt that their clinical team was safer when using the HoloLens2 to care for COVID-19 positive patients. Critically, this feedback suggests that these material improvements in safety and PPE use do not impact the quality nor consistency of care provided and may even enhance aspects of multi-professional care that have been hampered due to restrictions and changes in practice resulting from COVID-19. The provision of first-person hands-free audio and visual communication across a distributed team, together with the ability to introduce relevant health data via MR composites is an important development in telemedicine and has the potential for far wider applicability outside of the immediate response to COVID-19.

Limitations

This project suggests that substantial benefit could be obtained through the wider roll-out of MR based technology, however, this pilot project is not without its limitations. The technology has been deployed in a digitally mature organisation, and across clinical areas led by motivated and interested staff; as such there is a risk of early adopter bias, a deployment timeline that is not universally achievable, and the potential for this enthusiasm to have influenced the reported outcomes and provide an overestimation of its usability and practicality. In addition to this, the deployment within a single organisation in a non-blinded, randomised or controlled fashion may have led to the introduction of further bias and implications for the wider applicability of the findings. Further to the limitations in the methodology of this pragmatic pilot study, some issues with the technology were also highlighted. These included limited battery life, concerns around remote participants adequately hearing those not wearing the device such as patients, and stability and connection problems related to network speed and capacity. A key concern articulated by some users was that by providing distributed care, team members do not spend direct time with patients, which in turn may have negative consequences for future interactions and the overall quality of the doctor-patient relationship. Despite these valid concerns, patients themselves recognised the benefits presented by the technology: *"They are not only saving me... I am not passing anything*

onto them or their friends” (Patient).

In order to realise the potential benefits of this technology fully it is vital that further work is undertaken to understand better all aspects of its impact on care delivery, staff safety and patient outcomes. COVID-19 has led to a rapid expansion in the use of telemedicine and other digital technologies, but much of this has been understandably done at pace, without robust evaluation or assessment strategies, and often with little evidence for its safety, efficacy and cost effectiveness[21,22]. There is a need to demand a standardised process for effective governance, and robust and transparent evaluation strategies that encompass all aspects of the technology and how it impacts patients, hospitals and the staff that use it. In addition, there is a need to develop what is an off-the-shelf solution further so that it can better meet the context specific aspects of in-hospital care; for example the production of device specific protective face shields or the development of clinically focused software that allows more user-friendly blending of health data MR composites. The current ad-hoc use of generic software, whilst meeting the overall objective, limits future applications and potential impact.

Comparison with Prior Work

The use of electronic or smart PPE has been identified as having the potential to protect staff and conserve resources, while simultaneously providing rapid access to emergency care[11]. However, these have largely focused on mobile or desktop solutions rather than devices which are truly wearable, and often involve ad-hoc technology fixes. The use of hands-free MR technology allows for objective improvements in communication and situational awareness for all members of the team. Enabling remote MR-supported clinical assessments can enhance the ability of team members to recognise and respond to changes in a patient’s condition over and above that offered by more basic voice or video technologies[23]. The provision of first person, real-time audio and visual information allowed team members to “get a feel” for the patient they are consulting on despite physical distance. This was particularly evident for more junior members of the team who may previously have not been directly at the bedside during consultations. Further to providing equivalent, if not enhanced quality of care, obviating the physical presence of the majority of the clinicians on the ward significantly reduced the use of PPE. This is key to rationalise PPE use and may mitigate the significant supply chain disruption and equipment shortages that have been seen globally during the pandemic[24]. In addition to reducing the time clinicians spent exposed to harm and the amount of PPE utilised, the devices further minimised the risk of disease transmission by removing the need to handle equipment physically, such as computers, in the clinical environment.

Even with proper hand sanitisation and PPE use there is still the potential for contamination of portable medical equipment[25], and so reducing physical interaction is key in minimising risk. Finally, it is estimated that up to 7% of healthcare workers may have asymptomatic infection with COVID-19[26], and around 20% of COVID-19 infections in hospital inpatients are thought to be nosocomial[27]; the use of technology to reduce exposure may therefore also act to protect patients, as well as staff from disease spread.

When embarking on rapid response projects such as this it is important to select a relatively mature off-the-shelf technology, and only seek to make minor modifications. This ensures that there is background technical knowledge and awareness to help speed up deployment and aid with troubleshooting. In addition, by choosing or modifying existing technologies issues pertaining to data security and privacy should have already been explored and understood to some extent. Agility is needed in complying with data governance regulations when they themselves may rapidly change in response to a crisis[20]. However, once the initial response is complete and the transition to a mature embedded technology platform begins, an in-depth governance and security assessment must be undertaken to ensure full compliance with regulation and legislation, and to maintain the trust of users and patients. Choosing a mature technology also means that there may be some existing evidence for its efficacy and safety, although this is often not the case with new digital technologies[28]. It is essential to ensure that deployment is context specific as no two clinical areas possess the same workflows, structures and team practices. Final strategies for deployment and alignment to current workflows need to be flexible and driven by the clinical end-users. A clear evaluation plan must also be developed to ensure that efficacy, safety and impact are captured and disseminated rapidly and robustly. This will ensure that time and resource are not squandered on failing technologies, and potential benefits and successes are rapidly spread both locally and more widely. Linked to this requirement for robust evidence is a need to examine patient reported outcomes and measures of impact. It is crucial to ensure that patients perceive the quality and experience of their care to be at least maintained, if not improved with the deployment of new technologies; an area which was not explored in detail as part of this pilot study.

Contamination rates of personal devices in hospital can be over 30% and contribute to the risk of pathogen transmission[29]. The HoloLens2, like any head worn technology is reusable, and the risk of contamination is high. Therefore, when deployed such in high risk areas, particularly when airborne disease transmission is of greatest concern, effective protocols for cleaning and decontamination need to be developed and implemented as in this instance. Clear and easy to follow protocols for donning and doffing of the equipment must be developed locally, and effective training delivered to ensure that staff minimise the risk of device contamination, and do not put

themselves at risk of self-contamination and potential infection when using off the device[30,31]. It is important to include all end-users and subject matter experts in infection control when developing and implementing these procedures to ensure they are evidence-based, and that they pragmatically balance risk against ease of implementation and use to ensure optimal adherence and impact[32].

Conclusions

This pilot nested cohort study has shown that new technologies such as the HoloLens2 have a potentially important role to play when delivering care to patients with COVID-19; minimising staff and patient exposure to nosocomial infection risk, optimising the use of PPE and enhancing aspects of care. The technology has empowered a diverse group of clinicians to collaborate more effectively and efficiently, improved the transfer and dissemination of information and knowledge, and allowed care to be delivered more safely with reduced PPE demands. Initial experience of using the HoloLens2 in high-risk clinical areas is promising. What is now required is further development to cement the technology in day-to-day practice and the evolution of bespoke tools and applications that will enhance its capabilities. These developments must be coupled with robust objective evidence for its safety and effectiveness across a range of settings to ensure its impact on staff, patients and hospitals is fully realised.

Author's Contributions

GM, LK, AK, JC, CR, SP, AS, AT, PP and JK all contributed to the paper. GM, PP and JK designed and led the project. LK, AK, JC, CR, AS and AT led the clinical deployment of the technology. All authors contributed to the manuscript. JK was responsible for overall supervision and is guarantor for the study. All authors have access to all of the data and can take responsibility for the integrity of the data and accuracy of the data analysis. The PanSurg collaborative is a diverse group of clinicians and academics from Imperial College London undertaking a range of educational, clinical and research activities in support of the COVID pandemic response; this project represents part of that work.

Funding

The research was supported by the UK NIHR Biomedical Research Centre based at Imperial College Healthcare NHS Trust and Imperial College London. Microsoft Corporation (Redmond, WA, USA) provided in-kind support through the provision of technical assistance and supply of devices. This paper represents independent research. The funders, and specifically Microsoft Corporation, had no involvement in the study design; data collection, analysis and interpretation; writing of the report; or decision to submit the paper for publication.

Conflicts of Interests

James Kinross is a Clinical Advisor, and Philip Pratt the Chief Scientific Officer of Medical iSight; a 3D visualisation and surgical guidance software company. At the time of submission, no other authors declare further relationships or activities that could appear to have influenced the submitted work. Microsoft Corporation had no direct influence on how the study was executed or reported, however, the provision of in-kind support through the supply of devices and technical support is a potential conflict to acknowledge.

References

1. Moghadas SM, Shoukat A, Fitzpatrick MC, Wells CR, Sah P, Pandey A, Sachs JD, Wang Z, Meyers LA, Singer BH, Galvani AP. Projecting hospital utilization during the COVID-19 outbreaks in the United States. *Proc Natl Acad Sci U S A* [Internet] 2020;1–5. PMID:32245814
2. Emanuel EJ, Persad G, Upshur R, Thome B, Parker M, Glickman A, Zhang C, Boyle C, Smith M, Phillips JP. Fair allocation of scarce medical resources in the time of Covid-19. *N Engl J Med* 2020;1–7. PMID:32202722
3. PanSurg Collaborative. The three vital lessons Italian hospitals have learned in fighting covid-19 [Internet]. *Heal Serv J*. 2020 [cited 2020 May 24]. Available from: <https://www.hsj.co.uk/emergency-care/exclusive-the-three-vital-lessons-italian-hospitals-have-learned-in-fighting-covid-19/7027220.article>
4. Remuzzi A, Remuzzi G. COVID-19 and Italy: what next? *Lancet* [Internet] Elsevier Ltd; 2020;2:10–13. [doi: 10.1016/S0140-6736(20)30627-9]
5. Heneghan C, Oke J, Jefferson T. COVID-19 How many healthcare workers are infected? [Internet]. *Cent Evidence-Based Med*. 2020 [cited 2020 May 24]. Available from: <https://www.cebm.net/covid-19/covid-19-how-many-healthcare-workers-are-infected/>
6. Cook T, Kursumovic E, Lennane S. Deaths of NHS staff from covid-19 analysed. *Heal Serv J* [Internet] 2020 [cited 2020 May 18]; Available from: <https://www.hsj.co.uk/exclusive-deaths-of-nhs-staff-from-covid-19-analysed/7027471.article>
7. World Health Organization. Shortage of personal protective equipment endangering health workers worldwide [Internet]. 2020 [cited 2020 May 22]. Available from: <https://www.who.int/news-room/detail/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide>
8. The Lancet. COVID-19: protecting health-care workers. *Lancet* [Internet] Elsevier Ltd; 2020;395(10228):922. [doi: 10.1016/S0140-6736(20)30644-9]
9. Guest JL, Del Rio C, Sanchez T. The 3 steps needed to end the COVID-19 pandemic: bold public health leadership, rapid innovations, and courageous political will. *JMIR Public Heal Surveill* [Internet] 2020;6:1–4. PMID:32240972
10. UK's technological response to the COVID-19 healthcare crisis [Internet]. *Heal Tech Digit*. 2020 [cited 2020 May 18]. Available from: <https://www.healthtechdigital.com/uks-technological-response-to-the-covid-19-health-care-crisis/>

11. Turer R, Jones I, Rosenbloom T, Slovis C, Ward M. Electronic personal protective equipment: a strategy to protect emergency department providers in the age of COVID-19. *J Am Med Informatics Assoc* 2020;ocaa048. [doi: doi.org/10.1093/jamia/ocaa048]
12. Hollander J, Carr B. Virtually perfect? Telemedicine for COVID-19. *N Engl J Med* 2020;Mar 11. [doi: 10.1056/NEJMp2003539]
13. Pratt P, Ives M, Lawton G, Simmons J, Radev N, Spyropoulou L, Amiras D. Through the HoloLens™ looking glass: augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels. *Eur Radiol Exp European Radiology Experimental*; 2018;2(1):0–6. [doi: 10.1186/s41747-017-0033-2]
14. Zuo Y, Jiang T, Dou J, Yu D, Ndaro ZN, Du Y, Li Q, Wang S, Huang G. A novel evaluation model for a mixed-reality surgical navigation system: where microsoft HoloLens meets the operating room. *Surg Innov* 2020;27(2):193–202. [doi: 10.1177/1553350619893236]
15. Al Janabi HF, Aydin A, Palaneer S, Macchione N, Al-Jabir A, Khan MS, Dasgupta P, Ahmed K. Effectiveness of the HoloLens mixed-reality headset in minimally invasive surgery: a simulation-based feasibility study. *Surg Endosc* [Internet] Springer US; 2020;34(3):1143–1149. [doi: 10.1007/s00464-019-06862-3]
16. Tepper OM, Rudy HL, Lefkowitz A, Weimer KA, Marks SM, Stern CS, Garfein ES. Mixed reality with hololens: Where virtual reality meets augmented reality in the operating room. *Plast Reconstr Surg Lippincott Williams and Wilkins*; 2017;140(5):1066–1070. [doi: 10.1097/PRS.0000000000003802]
17. Moro C, Štromberga Z, Raikos A, Stirling A. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anat Sci Educ* [Internet] John Wiley and Sons Inc.; 2017 Nov 1 [cited 2020 Jul 13];10(6):549–559. [doi: 10.1002/ase.1696]
18. Sittig D, Singh H. A new sociotechnical model for studying health information technology in complex adaptive healthcare systems. *Qual Saf Healthc* 2010;19 Suppl 3(1):i68–i74. PMID:20959322
19. NHS Digital. Messaging tool for NHS to support remote working during coronavirus outbreak [Internet]. 2020 [cited 2020 May 24]. Available from: <https://digital.nhs.uk/news-and-events/latest-news/messaging-tool-for-nhs-to-support-remote-working-during-coronavirus-outbreak>
20. NHSX. COVID-19 information governance advice for staff working in health and care organisations [Internet]. 2020 [cited 2020 May 24]. Available from: <https://www.nhsx.nhs.uk/covid-19-response/data-and-information-governance/information-governance/covid-19-information-governance-advice-health-and-care-professionals/>

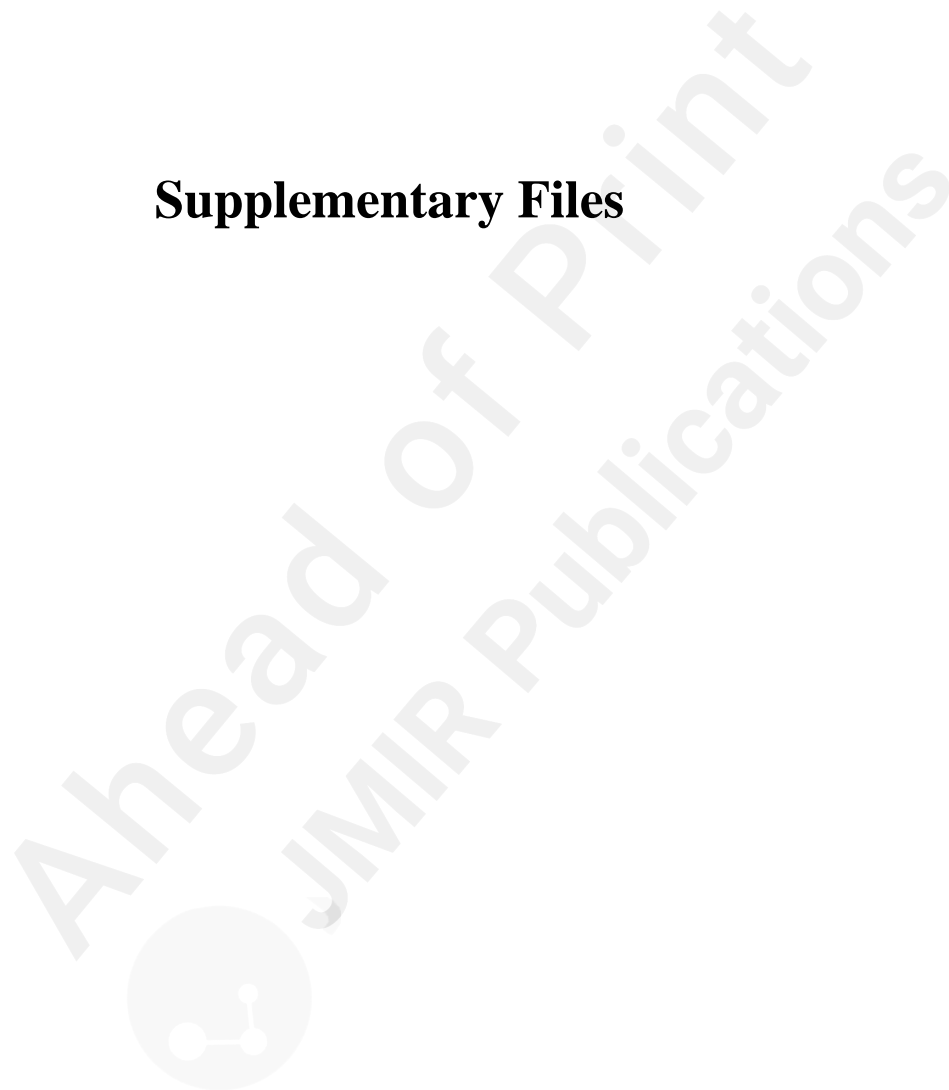
21. Mann D, Chen J, Chunara R, Testa P, Nov O. COVID-19 transforms health care through telemedicine: evidence from the field. *J Am Med Informatics Assoc* [Internet] 2020 [cited 2020 May 27]; PMID:32324855
22. Ting DSW, Carin L, Dzau V, Wong TY. Digital technology and COVID-19. *Nat Med. Nature Research*; 2020. p. 459–461. PMID:32284618
23. Callaghan A, Kinsman L, Cooper S, Radomski N. The factors that influence junior doctors' capacity to recognise, respond and manage patient deterioration in an acute ward setting: An integrative review. *Aust Crit Care. Elsevier Ireland Ltd*; 2017. p. 197–209. PMID:27726906
24. World Health Organization. Rational use of personal protective equipment for coronavirus disease (COVID-19) and considerations during severe shortages [Internet]. 2020 [cited 2020 May 27]. Available from: [https://www.who.int/publications-detail/rational-use-of-personal-protective-equipment-for-coronavirus-disease-\(covid-19\)-and-considerations-during-severe-shortages](https://www.who.int/publications-detail/rational-use-of-personal-protective-equipment-for-coronavirus-disease-(covid-19)-and-considerations-during-severe-shortages)
25. Jinadatha C, Villamaria F, Coppin J, Dale C, Williams M, Whitworth R, Stibich M. Interaction of healthcare worker hands and portable medical equipment: A sequence analysis to show potential transmission opportunities. *BMC Infect Dis BioMed Central Ltd.*; 2017 Dec 28;17(1). [doi: 10.1186/s12879-017-2895-6]
26. Treibel T, Manisty C, Burton M, McKnight Á, Lambourne J, Augusto J, Couto-Parada X, Cutino-Moguel T, Noursadeghi M, Moon J. COVID-19: PCR screening of asymptomatic health-care workers at London hospital. *Lancet Elsevier BV*; 2020 May 23;395(10237):1608–1610. [doi: 10.1016/s0140-6736(20)31100-4]
27. Evans S, Agnew E, Vynnycky E, Robotham J V. The impact of testing and infection prevention and control strategies on within-hospital transmission dynamics of COVID-19 in English hospitals. *medRxiv Cold Spring Harbor Laboratory Press*; 2020 May 20;2020.05.12.20095562. [doi: 10.1101/2020.05.12.20095562]
28. Martin G, Khajuria A, Arora S, King D, Ashrafian H, Darzi A. The impact of mobile technology on teamwork and communication in hospitals: A systematic review. *J Am Med Informatics Assoc* 2019;26(4):339–355. [doi: 10.1093/jamia/ocy175]
29. Haun N, Hooper-Lane C, Safdar N. Healthcare personnel attire and devices as fomites: a systematic review. *Infect Control Hosp Epidemiol. Cambridge University Press*; 2016. p. 1367–1373. [doi: 10.1017/ice.2016.192]
30. Kwon J, Burnham CA, Reske K, Liang S, Hink T, Wallace MA, Shupe A, Seiler S, Cass C, Fraser V, Dubberke E. Assessment of healthcare worker protocol deviations and self-contamination during personal protective equipment donning and doffing. *Infect Control Hosp*

Epidemiol Cambridge University Press; 2017 Sep 1;38(9):1077–1083. [doi: 10.1017/ice.2017.121]

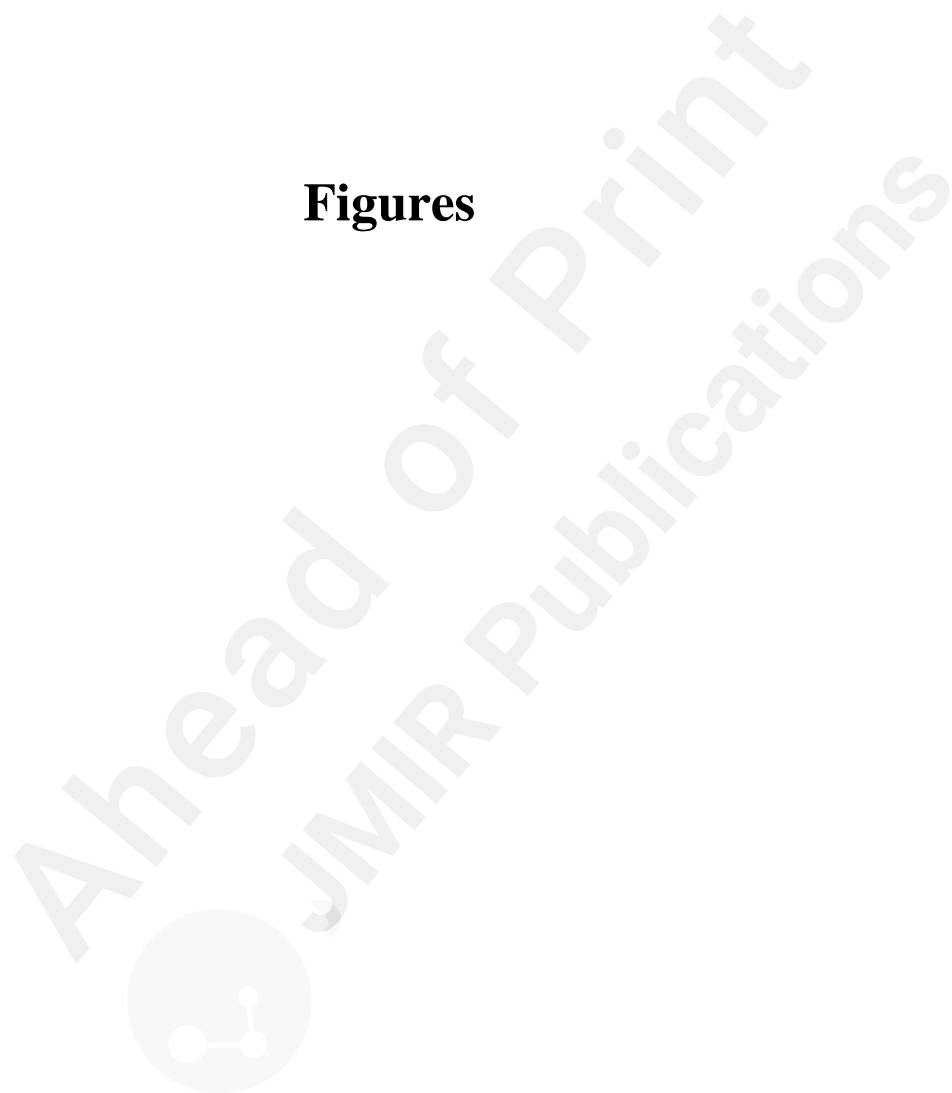
31. Okamoto K, Rhee Y, Schoeny M, Lolans K, Cheng J, Reddy S, Weinstein RA, Hayden MK, Popovich KJ. Impact of doffing errors on healthcare worker self-contamination when caring for patients on contact precautions. *Infect Control Hosp Epidemiol Cambridge University Press*; 2019 May 1;40(5):559–565. [doi: 10.1017/ice.2019.33]
32. Houghton C, Meskell P, Delaney H, Smalle M, Glenton C, Booth A, Chan XHS, Devane D, Biesty LM. Barriers and facilitators to healthcare workers' adherence with infection prevention and control (IPC) guidelines for respiratory infectious diseases: a rapid qualitative evidence synthesis. *Cochrane Database Syst Rev Wiley*; 2020 Apr 21;4(4). PMID:32315451



Supplementary Files



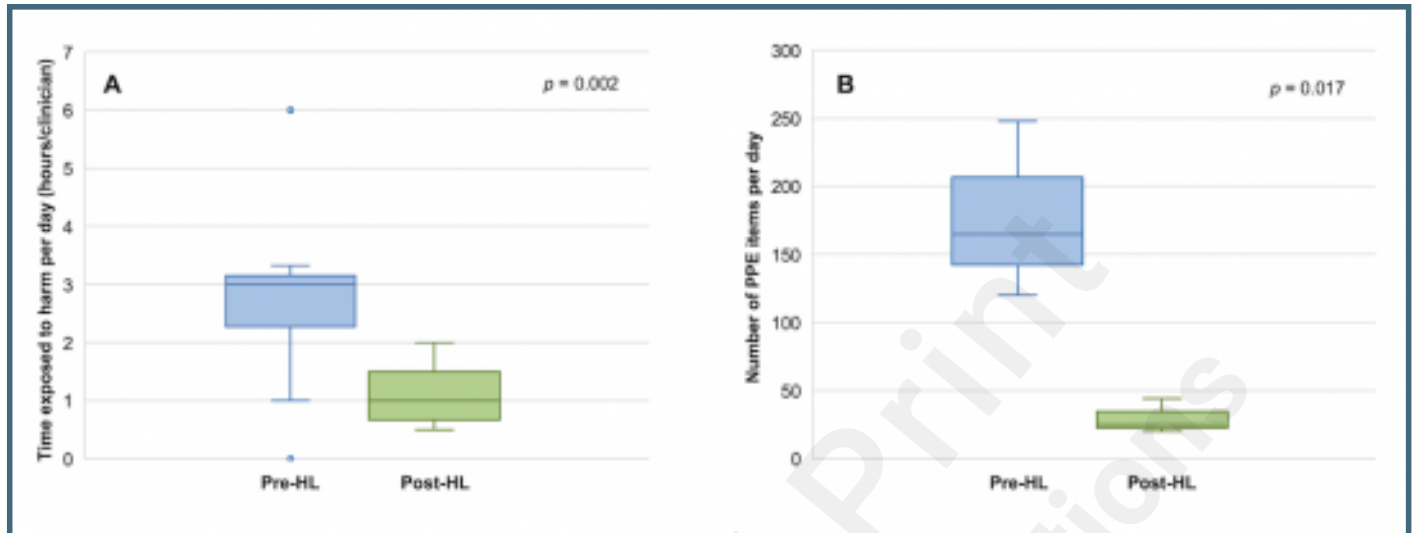
Figures



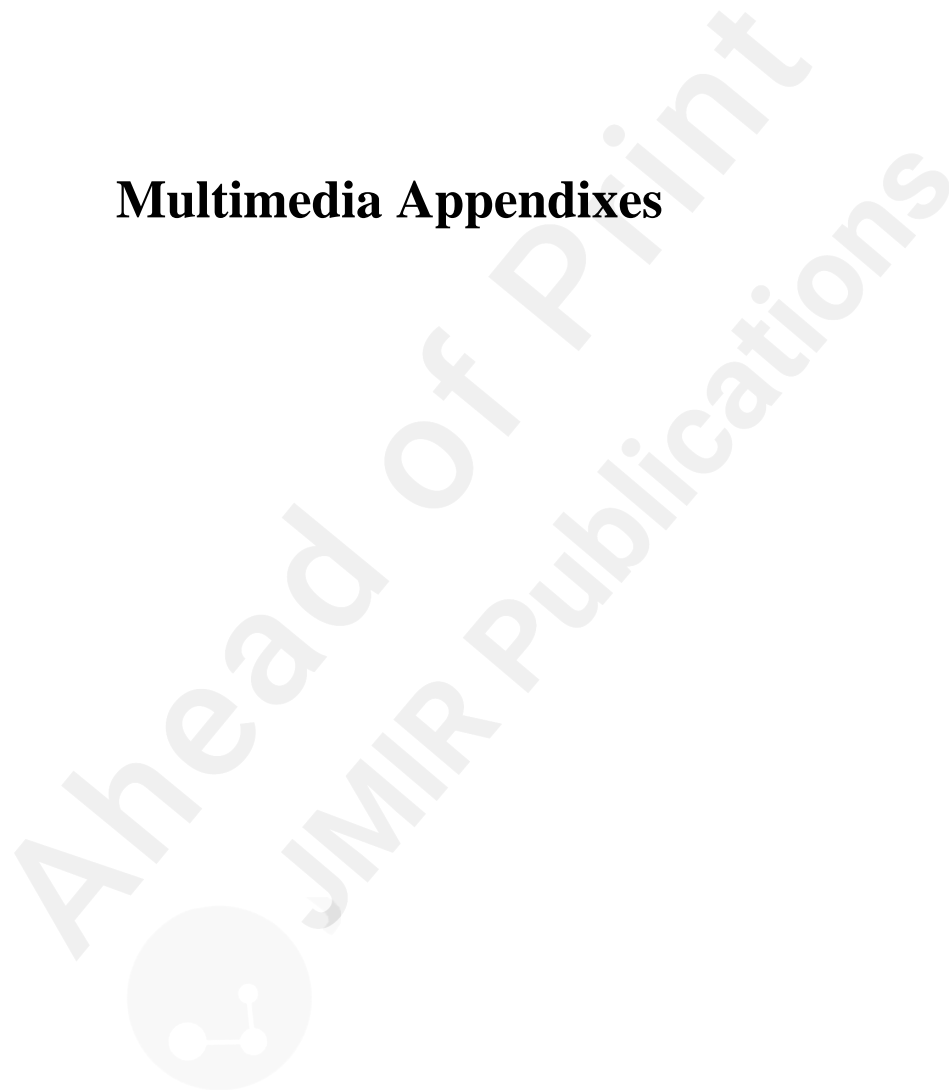
Images demonstrating use and functionality of the Hololens2™. 1A) View of end-user in PPE wearing the device. 1B) View of remote clinical team engaging in clinical round from a safe location. 1C) First-person view through the Hololens2™ showing the remote clinical team and relevant imaging placed in the user's field of view as Mixed Reality composites (image generated with staff to ensure protection of patient privacy and data).



Aggregate data on staff exposure to risk and PPE use across three clinical areas before and after Hololens2™ (HL) deployment. 2A) reduction in time (hours/day/staff member) exposed to high-risk COVID-19 environments (3.32 vs. 1.63 hours, $t=3.21$, $p=0.002$). 2B) reduction in the mean number of PPE items used (178 vs. 30, $t=3.88$, $p=0.017$).



Multimedia Appendixes



Suggested protocol for donning/doffing and decontamination of the HoloLens device.
URL: <https://asset.jmir.pub/assets/d2785653cb8e72abc08ad91c23a2ef7d.pdf>

