Original research

SARS-CoV-2 seroprevalence and asymptomatic viral carriage in healthcare workers: a cross-sectional study

Adrian Shields,1,2 Sian E Faustini,1 Marisol Perez-Toledo,3 Sian Jossi,3 Erin Aldera,4 Joel D Allen,3 Saly Al-Taei,1 Claire Backhouse,1 Andrew Bosworth,2 Lyndsey A Dunbar,1 Daniel Ebanks,1 Beena Emmanuel,1 Mark Garvey,2,4 Joanna Gray,2,1 I Michael Kidd,6 Golaleh McGinnell,2 Dee E McLoughlin,7 Gabriella Morley,7 Joanna O’Neill,2 Danai Papakonstantinou,4 Oliver Pickles,8 Charlotte Poxon,8 Megan Richter,1 Eloise M Walker,4 Kasun Wanigasooriya,8 Yasunori Watanabe,5,9 Celina Whalley,8 Agnieszka E Zielinska,4 Max Crispin,5 David C Wraith,3,10 Andrew D Beggs,8 Adam F Cunningham,3 Mark T Drayson,1,10 Alex G Richter1,2

ABSTRACT

Objective To determine the rates of asymptomatic viral carriage and seroprevalence of SARS-CoV-2 antibodies in healthcare workers.

Design A cross-sectional study of asymptomatic healthcare workers undertaken on 24/25 April 2020.

Setting University Hospitals Birmingham NHS Foundation Trust (UHBFT), UK.

Participants 545 asymptomatic healthcare workers were recruited while at work. Participants were invited to participate via the UHBFT social media. Exclusion criteria included current symptoms consistent with COVID-19. No potential participants were excluded.

Intervention Participants volunteered a nasopharyngeal swab and a venous blood sample that were tested for SARS-CoV-2 RNA and anti-SARS-CoV-2 spike glycoprotein antibodies, respectively. Results were interpreted in the context of prior illnesses and the hospital departments in which participants worked.

Main outcome measure Proportion of participants demonstrating infection and positive SARS-CoV-2 serology.

Results The point prevalence of SARS-CoV-2 viral carriage was 2.4% (n=13/545). The overall seroprevalence of SARS-CoV-2 antibodies was 24.4% (n=126/516). Participants who reported prior symptomatic illness had higher seroprevalence (37.5% vs 17.1%, χ²=21.1034, p<0.0001) and quantitatively greater antibody responses than those who had remained asymptomatic. Seroprevalence was greatest among those working in housekeeping (34.5%), acute medicine (33.3%) and general internal medicine (30.3%), with lower rates observed in participants working in intensive care (14.8%). BAME (Black, Asian and minority ethnic) ethnicity was associated with a significantly increased risk of seropositivity (OR: 1.92, 95% CI 1.14 to 3.23, p=0.01). Working on the intensive care unit was associated with a significantly lower risk of seropositivity compared with working in other areas of the hospital (OR: 0.28, 95% CI 0.09 to 0.78, p=0.02).

Conclusions and relevance We identify differences in the occupational risk of exposure to SARS-CoV-2 between hospital departments and confirm asymptomatic seroconversion occurs in healthcare workers. Further investigation of these observations is required to inform future infection control and occupational health practices.

Key messages

What is the key question?
► What are the rates of asymptomatic viral carriage and the seroprevalence of SARS-CoV-2 antibodies in UK healthcare workers?

What is the bottom line?
► In this study, the point prevalence of SARS-CoV-2 viral carriage was 2.4% and the overall seroprevalence of SARS-CoV-2 antibodies was 24.4%.

Why read on?
► This study identifies differences in the risk of exposure of healthcare workers to SARS-CoV-2 between ethnic groups and between hospital departments; these findings may inform future infection control and occupational health policy.

INTRODUCTION

Healthcare workers are critical to the ongoing response to the SARS-CoV-2 pandemic. During the course of their work, they are exposed to hazards that place them at risk of infection.1 Previous studies have shown infection rates of up to 14% in symptomatic and 7.1% in asymptomatic healthcare workers,2 3 which are higher than general population studies reported to date and suggest an occupational risk.

Antibody responses have been demonstrated post infection with SARS-CoV-2, but it is not yet known whether these correlate with immunity, or how long antibody titres will be maintained. The magnitude of antibody responses appears proportional to age and severity of infection suffered.4 Asymptomatic seroconversion following exposure to SARS-CoV
and SARS-CoV-2 have been documented in small cohorts; again the quality and longevity of these immunological responses are unknown.13

Understanding the relationship between infection, symptomatology and the subsequent serological responses is critical to understanding herd immunity, vaccine deployment and safeguarding the workforce. Seroprevalence studies provide the foundation to inform this understanding.

University Hospitals Birmingham NHS Foundation Trust (UHBFT) is one of the largest hospital trusts in the UK with over 20 000 employees delivering care to 2.2 million people per annum. We conducted a cross-sectional study of 354 staff at UHBFT to determine the point prevalence of infection and seroprevalence of SARS-CoV-2 antibodies in healthcare workers and their relationship to prior symptoms of COVID-19 and the hospital departments in which participants worked.

METHODS
A cross-sectional study of asymptomatic healthcare workers at UHBFT was undertaken, recruiting 345 individuals who were at work over the course of 24 hours between 24 and 25 April 2020. Initial invitation to participate in the study was made via social media. There was no predefined sample size; participants self-reported for enrolment. Individuals were excluded if they reported symptoms of COVID-19 on the day. Individuals self-isolating at home due to personal symptomatic illnesses or illnesses in household contacts in the previous 2 weeks were indirectly excluded from the study.

All individuals volunteered a nasopharyngeal swab for SARS-CoV-2 RNA detection and a venous blood sample for anti-SARS-CoV-2 spike glycoprotein serology, tested using an ELISA developed inhouse by the University of Birmingham Clinical Immunology Service. Detection of SARS-CoV-2 RNA was performed using real-time PCR (Viasure, CerTest Biotec) directed against the ORF1ab and N genes following guanidine isothiocyanate inactivation of nasopharyngeal swabs. Serological analysis was performed using a high-sensitivity ELISA developed inhouse by the University of Birmingham Clinical Immunology Service. Serological analysis was performed at biological containment level 2. High-binding plates (Greiner Bio-One) were coated with trimeric SARS-CoV-2 spike glycoprotein and blocked with StabilCoat solution (Sigma-Aldrich). Serum was prediluted 1:40 prior to analysis. A combined secondary layer containing horseradish peroxidase conjugated ovine polyclonal antibodies against IgG, IgA and IgM followed by 3,3′,5,5′-tetramethylbenzidine development was used to detect the presence of antibodies. The cut-off for positivity on the ELISA was set at 2 SD above the mean OD450 of eight pre-2019 negative sera run independently across seven separate plates.

Prior validation of this assay has shown it demonstrates 100% sensitivity in individuals with PCR-proven disease 7 days post symptom onset (n=59 hospitalised, n=31 community) and 97.8% specificity based on 270 individual negative pre-2019 samples. Intra-assay coefficient of variation (CV%) is 1.58% and interassay CV% is 7.5% for negative controls and 17.3% for positive controls and 7.2% for controls running at the cut-off of positivity on the assay.

Serological analysis was performed at biological containment level 2. High-binding plates (Greiner Bio-One) were coated with trimeric SARS-CoV-2 spike glycoprotein and blocked with StabilCoat solution (Sigma-Aldrich). Serum was prediluted 1:40 prior to analysis. A combined secondary layer containing horseradish peroxidase conjugated ovine polyclonal antibodies against IgG, IgA and IgM followed by 3,3′,5,5′-tetramethylbenzidine development was used to detect the presence of antibodies. The cut-off for positivity on the ELISA was set at 2 SD above the mean OD450 of eight pre-2019 negative sera run independently across seven separate plates.

RESULTS
The point prevalence of PCR positivity in asymptomatic healthcare workers was 2.4% (n=13/545). Of these individuals, 15.4% (n=2/13) had detectable anti-SARS-CoV-2 antibodies in their serum and 38.4% (n=5/13) subsequently became unwell with symptoms consistent with COVID-19. Serum was available for analysis on 516 individuals, and 26.3% (n=136/516) of participants reported a prior illness consistent with COVID-19 (table 1). The overall seroprevalence across the cohort was 24.4% (n=126/516); individuals reporting a prior symptomatic illness had significantly greater seroprevalence than those who had remained asymptomatic throughout the time period assessed (36.8% vs 17.1%, χ2=19.75, p<0.0001) (figure 1A). Antibody responses in individuals who had experienced a prior symptomatic illness were quantitatively greater than those who remained asymptomatic (Kruskal-Wallis statistics 7.159, p=0.02, Dunn’s post-test comparison of symptomatic vs asymptomatic individuals: mean rank difference 17.02, adjusted p=0.02) (figure 1B).

We explored the relationship between the timing of healthcare worker illness associated with seropositivity and weekly trust-wide COVID-19 mortality, as a surrogate of overall patient burden (figure 1C). Illnesses associated with positive serology were occurring for over 3 weeks prior to UK lockdown. The temporal pattern of reported symptomatic illnesses associated with seropositivity in healthcare workers preceded that of trust-wide deaths by approximately 1 week. The highest incidence of symptomatic illness associated with seropositivity (77.8%, n=14/18) was observed in the week beginning 28 March 2020, 1 week before peak weekly mortality was reached within UHBFT.
Seroprevalence was mapped to the departments where individuals worked within UHBFT (figure 1D). Seroprevalence was highest in those working in housekeeping (34.5%, n=10/29), acute medicine (33.3%, n=10/30) and general internal medicine (30.3%, n=30/99) and lowest in participants working in intensive care (14.8%, n=9/61), emergency medicine (13.3%, n=2/15) and general surgery (13.0%, n=3/23). Using intensive care as a reference population, an increased RR of seropositivity was observed for those working in housekeeping (RR 2.34, CI 1.08 to 5.01, p=0.03), acute medicine (RR 2.05, CI 1.08 to 4.05, p=0.03) and general internal medicine (RR 1.07 to 5.01, p=0.03), acute medicine (RR 2.25, CI 1.04 to 4.46, p=0.04) and general internal medicine (RR 2.05, CI 1.08 to 4.05, p=0.03).

Univariate and multivariate analyses were undertaken using serostatus as the dependent variable and incorporating participant age, sex, ethnicity, Index of Multiple Deprivation score of participants’ postcodes and the hospital departments where participants worked as independent variables (table 2). Women had a higher seroprevalence than men (26.3% vs 18.8%), but this difference was not statistically significant in univariate or multivariate analysis (adjusted OR: 1.92, 95% CI 1.07 to 3.23, p=0.07). Univariate and multivariate analyses both demonstrated individuals of BAME (Black, Asian and minority ethnic) ethnicity were at significantly greater risk of seropositivity than individuals of white ethnicity (adjusted OR: 1.92, 95% CI 1.14 to 3.23, p=0.01). Working in intensive care medicine was associated with significantly reduced risk of seropositivity in multivariate analysis (adjusted OR: 0.28, 95% CI 0.09 to 0.78, p=0.02).

On average, the Index of Multiple Deprivation score was significantly lower in the home postcodes of BAME participants compared with white participants (−0.570 vs −0.232, t=3.747, p=0.0002). However, no significant differences between any individual government indices of deprivation were observed between individuals who were seropositive and seronegative in this study (table 3). Furthermore, in multiple logistic regression analysis, the Index of Multiple Deprivation did not influence serostatus in this study (OR 0.99, 95% CI 0.7387 to 1.323, p=0.9503). This supports an interpretation that the observed difference in seroprevalence rates in this cohort is more likely due to occupational risk, rather than external factors.

**DISCUSSION**

In this cross-sectional study of asymptomatic healthcare workers, the point prevalence of SARS-CoV-2 nasopharyngeal carriage (2.4%) was concordant with a contemporaneous UK study but less than an earlier study performed during the peak of the pandemic (cumulative total 14.0%). The relatively low prevalence of viral RNA carriage in our cohort appears to be in keeping with the national epidemiology of the first wave of the UK SARS-CoV-2 epidemic. In contrast, we report a higher overall SARS-CoV-2 seroprevalence of 24.4%. This suggests the cumulative infection rate determined using molecular testing should have been far higher than was reported in previous studies. This is consistent with data demonstrating the relative insensitivity of nasopharyngeal swabs in determining viral carriage, but may also reflect access to testing. With respect to the assay used to determine seropositivity, the coefficient of variance of internal quality control material designed to run close to the clinical cut-off of the assay was 7.2%, suggesting that true seroprevalence lies between 23.8% and 26.0% based on the data from our cohort. Thus, the overall seroprevalence of SARS-CoV-2 antibodies in healthcare workers in this study is significantly greater than the 6% seroprevalence in the general population of the Midlands region determined by Public Health
Respiratory infection

Figure 1  (A) Seroprevalence rates in study participants self-reporting prior symptomatic illnesses consistent with COVID-19 compared with asymptomatic individuals. (B) Optical density (OD) of anti-SARS-CoV-2 antibodies in individuals with positive serology classified by self-reported prior symptomatic illness (n=126). Line shows the median value of each group. (C) Timing of prior symptomatic illness in study participants and their relationship with seroprevalence of SARS-CoV-2 antibodies, total inpatients at UHBFT who had tested positive for SARS-CoV-2 by PCR and overall UHBFT-wide deaths in the weeks of March and April 2020. (D) Seroprevalence of SARS-CoV-2 antibody in study participants by department in which they work. AMU, acute medical unit; ED, emergency department; ITU, intensive care unit; OBGYN, obstetrics and gynaecology; OPD, outpatient department; R&D, research and development; UHBFT, University Hospitals Birmingham NHS Foundation Trust.

England. Data from two other studies also found elevated infection or seroprevalence in healthcare workers compared with the general population. Collectively, these studies suggest a marked occupational risk of exposure to SARS-CoV-2 associated with healthcare work during the COVID-19 pandemic.

We identify variation in the seroprevalence of SARS-CoV-2 antibodies among different groups of healthcare workers. The highest seroprevalence was observed in housekeepers (34.5%) and those working in acute medicine (33%) or general internal medicine (30.3%), with lower seroprevalence among participants working in intensive care medicine (14.8%). Multiple logistic regression confirmed a significantly lower risk of seropositivity in individuals working in intensive care medicine. This strongly supports the conclusion that differential risk of SARS-CoV-2 exposure exists within the hospital environment. The reasons underlying this are likely to be multifactorial: in accordance with national guidelines, intensive care units were designated high-risk environments and the use of enhanced personal protective equipment (PPE) including filtered face piece (class 3) respirators mandated. In contrast, fluid-resistant surgical masks were recommended in other clinical areas. The contribution of enhanced PPE in protecting staff from infection with SARS-CoV-2 should be studied further, including the availability of training, space and supervision to use PPE effectively. Differential occupational exposure to severe respiratory viruses was previously observed during the 2003 SARS-CoV outbreak.

We demonstrate that BAME ethnicity confers a significantly increased risk of seropositivity in this study. Although individuals of BAME ethnicity within this study, on average, lived in significantly more deprived areas, the Index of Multiple Deprivation score of participants’ home postcode did not significantly influence serostatus within our multiple logistic regression model. It is not clear from our study whether this increased risk of seropositivity arises from a greater risk of exposure to the virus, or a greater risk of infection if exposed to the SARS-CoV-2 virus. Regardless of the cause, this finding demands urgent further investigation, particularly in view of the ethnic disparities in the outcome from COVID-19.

We demonstrate viral carriage in 2.4% of asymptomatic participants and positive SARS-CoV-2 serology in the absence of BAME ethnicity within this study, on average, lived in significantly more deprived areas, the Index of Multiple Deprivation score of participants’ home postcode did not significantly influence serostatus within our multiple logistic regression model.
of prior symptomatology in 17.1%. Using similar immunological methods, Hains et al. reported seroconversion in 44.0% (n=11/25) of healthcare workers in a US dialysis unit, including asymptomatic seroconversion. It is not known whether asymptomatic viral carriage leads to transmission in the hospital setting and it is not possible to interrogate this retrospectively. However, our data would support the assessment of widespread healthcare worker testing, including track and trace, on viral transmission during future waves of a pandemic.

Finally, in keeping with previous studies that have correlated the severity of COVID-19 with the magnitude of the consequent antibody response, we demonstrate that antibody responses, on average, significantly greater in individuals with prior symptomatic illness compared with those who remained asymptomatic. Further studies must determine the neutralising capacity of antibody responses associated with different severities of disease, the titres at which neutralising antibodies provide protection against infection and the duration of that protection.

There are a number of limitations to our cross-sectional study. Participants self-presented to enrol, which may introduce bias in the study cohort; however, the balance of participants working in intensive care, acute medicine and general internal medicine represents a fair reflection of frontline staff caring for patients with COVID-19. Both acute and non-acute, non-patient-facing occupational groups were recruited to enable comparison. Data were not available to determine how representative our sampling was through comparison of the numbers recruited to individual groups with the total number of staff at work on the day of the study. By failing to capture more recent infections leading to seroconversion, this may underestimate the true seroprevalence, although this study would have captured the peak of the pandemic. The relationship between symptomatic illness and antibody positivity requires confirmation in larger studies, particularly given that 19.2% (n=99/516) of participants did not provide information about whether they had suffered a prior symptomatic illness before serological analysis was undertaken. Further studies are necessary to consider whether the increased risk of seropositivity observed within individuals of BAME ethnicity is homogeneous throughout the individual ethnic populations that collectively constitute the BAME group. Finally, longitudinal studies will be required to demonstrate the persistence of current seropositivity and to directly attribute seroconversion events to PCR-proven SARS-CoV-2 infection.

In conclusion, we document the high seroprevalence of SARS-CoV-2 antibodies in healthcare workers with and without prior symptomatic illness and identify the groups of workers who have significantly different seroprevalence, suggesting differential occupational risk.

### Table 2

| Variable | Unadjusted OR | 95% CI | P value | Z | Adjusted OR | 95% CI | Z | P value |
|----------|--------------|-------|---------|---|-------------|-------|---|---------|
| Age      | --           | --    | --      | 0.98 | 0.96 to 1.00 | 0.60 | 0.55 |
| Sex (female) | 1.54 | 0.94 to 2.56 | 0.09 | 1.72 | 1.49 | 0.81 to 2.83 | 1.79 | 0.07 |
| Ethnicity (BAME) | 1.58 | 1.01 to 2.49 | 0.05 | 1.97 | 1.92 | 1.14 to 3.23 | 1.26 | 0.01 |
| Index of Multiple Deprivation score | -- | -- | -- | 0.99 | 0.74 to 1.32 | 2.46 | 0.95 |
| Acute medicine | 1.60 | 0.76 to 3.37 | 0.24 | 1.17 | 0.99 | 0.34 to 2.86 | 0.01 | 0.99 |
| Emergency department | 0.47 | 0.10 to 1.81 | 0.31 | 1.01 | 0.36 | 0.05 to 1.69 | 1.19 | 0.23 |
| Estates | 0.61 | 0.18 to 2.00 | 0.43 | 0.78 | 0.57 | 0.11 to 2.29 | 0.75 | 0.45 |
| General internal medicine | 1.45 | 0.89 to 2.32 | 0.13 | 1.52 | 0.93 | 0.42 to 2.12 | 0.17 | 0.86 |
| General surgery | 0.45 | 0.14 to 1.37 | 0.19 | 1.30 | 0.24 | 0.03 to 1.05 | 1.71 | 0.09 |
| Facilities | 0.71 | 0.29 to 1.63 | 0.41 | 0.81 | 0.52 | 0.15 to 1.60 | 1.10 | 0.45 |
| Housekeeping | 1.68 | 0.79 to 3.62 | 0.19 | 1.30 | 1.01 | 0.31 to 3.09 | 0.02 | 0.99 |
| Intensive care | 0.50 | 0.24 to 1.01 | 0.06 | 1.87 | 0.28 | 0.09 to 0.78 | 2.37 | 0.02 |
| Obstetrics and gynaecology | 1.34 | 0.63 to 2.71 | 0.44 | 0.78 | 0.85 | 0.30 to 2.39 | 0.30 | 0.77 |
| Research and development | 0.71 | 0.33 to 1.50 | 0.38 | 0.88 | 0.44 | 0.15 to 1.22 | 1.54 | 0.12 |

Unadjusted OR and adjusted OR following multiple logistic regression are presented. OR presented for individual hospital departments represents the odds of seropositivity for individuals working in that department compared with not working in that department. Statistically significant OR are in bold (p<0.05).

The area under the receiver operating characteristic curve of this model was 0.675 (95% CI 0.619 to 0.732, p<0.0001).

BAME, Black, Asian and minority ethnicity.

### Table 3

| Index of deprivation | Seropositive | Seronegative | P value |
|----------------------|--------------|--------------|---------|
| Index of Multiple Deprivation | −0.395 (0.89) | −0.345 (0.79) | 0.58 |
| Income               | −0.352 (0.99) | −0.316 (0.80) | 0.69 |
| Employment           | −0.267 (1.00) | −0.312 (0.78) | 0.61 |
| Education and skills | −0.149 (0.87) | −0.160 (0.76) | 0.90 |
| Health and disability| −0.361 (0.73) | −0.347 (0.60) | 0.84 |
| Barriers to housing and services | −0.446 (0.57) | −0.333 (0.60) | 0.07 |
| Living environment   | −0.433 (0.78) | −0.444 (0.71) | 0.88 |
| Income deprivation affecting children | −0.381 (0.93) | −0.333 (0.80) | 0.59 |
| Income deprivation affecting older adults | −0.369 (0.88) | −0.274 (0.75) | 0.25 |

Mean and SD (in parentheses) are provided. Numerically lower values represent more deprived postcodes. Means of seropositive and seronegative groups were compared using the unpaired, two-tailed Student’s t-test.

### Table 1

The area under the receiver operating characteristic curve of this model was 0.675 (95% CI 0.619 to 0.732, p<0.0001).
Respiratory infection

5School of Biological Sciences, University of Southampton, Southampton, UK
6Public Health England Midlands and East Region, Birmingham, UK
7Institute of Inflammation and Ageing, University of Birmingham, Birmingham, UK
8Surgical Research Laboratory, Institute of Cancer and Genomic Sciences, University of Birmingham, Birmingham, UK
9Oxford Glycobiology Institute, Department of Biochemistry, University of Oxford, Oxford, UK
10University Hospitals Birmingham NHS Foundation Trust and University of Birmingham, NIHR Biomedical Research Centre, Birmingham, UK

Twitter Adrian Shields @immunologydoc, Mark Garvey @drmarkgarvey, David C Wraith @cameron_wraith and Alex G Richter @AlexRichter3

Acknowledgements The authors would like to acknowledge the staff of the Clinical Immunology Service who helped process the samples for PCR and serological testing, Dr Margaret Goodall for her expertise in antibody production and assay development, and Dr Jason McLellan for the expression plasmid for the SARS-CoV-2 glycoprotein. The authors would also like to acknowledge all the participants from UHBFT. Serological assay development was undertaken in collaboration with The Binding Site Group. An earlier version of this manuscript was uploaded on 19 May 2020 to the preprint server MedRxiv (doi: https://doi.org/10.1101/2020.05.18.20105197).

Contributors AS helped conceive the study, collated and analysed the data, produced the figures, and wrote and revised the manuscript. SEF helped conceive the study, performed the experiments, and collated and analysed the data. MP-T and SJ performed the experiments, and collated and analysed the data. JDA, YW and MC produced the original trimeric spike-glycoprotein on which the serological assays are based and advised on methodology. JG, GoM and JON recruited participants to the study, facilitated the acquisition of clinical samples and collated the study results. MG collated and interpreted trust-level data on infections within UHBFT inpatients. IMK, AB and ADB supported the establishment and validation of the PCR workflow at the University of Birmingham. EA, DEM, GaM, DP, EMW and AEZ facilitated the establishment of RNA extraction and viral inactivation workflow within the category 3 biosafety laboratory at the University of Birmingham. KW, OP, CP and CW undertook PCR assays for the study. SA-T, CB, LAD, DE, BE and MR processed the samples, undertook the experiments and collated the results for serological studies. DCW, AFC and MTD helped conceive the study and supervised the analysis of data from the study. AGR is the senior and corresponding author for this manuscript and provided overall leadership for all aspects of the study. All authors helped revise the manuscript for publication.

Funding This study was funded internally by the University of Birmingham and University Hospitals Birmingham NHS Foundation Trust and carried out at the National Institute for Health Research (NIHR)/Wellcome Trust Birmingham Clinical Research Facility. This paper presents independent research supported by the NIHR Birmingham Biomedical Research Centre at the University Hospitals Birmingham NHS Foundation Trust and the University of Birmingham. Laboratory studies were undertaken by the Clinical Immunology Service, University of Birmingham. Work in MC’s laboratory was funded by the International AIDS Vaccine Initiative, Bill and Melinda Gates Foundation through the Collaboration for AIDS Vaccine Discovery (OPP1084519 and OPP1115782), the Scripps Consortium for HIV Vaccine Development (CHAVD) (AI144462), and the University of Southampton Coronavirus Response Fund which has over 1000 donors from around the world. ADB is currently supported by a Cancer Research UK Advanced Clinician Scientist award (C31641/A23923) and his laboratory is supported by CRUK Centre Birmingham (C17422/A25154) and the Birmingham Experimental Cancer Medicine Centre (C11497/A25127).

Disclaimer The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Competing interests MTD reports personal fees from Abingdon Health, outside the submitted work. All other authors declare no competing interests.

Patient consent for publication Not required.

Ethics approval The study was approved by the London - Camden and Kings Cross Research Ethics Committee (reference 20/HRA/1817).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Proposals should be directed to the corresponding author.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution 4.0 Unported (CC BY 4.0) license, which permits others to copy, redistribute, remix, transform and build upon this work for any purpose, provided the original work is properly cited, a link to the licence is given, and indication of whether changes were made. See: https://creativecommons.org/licenses/by/4.0/.

REFERENCES
1 Chen W-Q, Lu C-Y, Yong T-W, et al. Anti-Sars-Cov immunoglobulin G in healthcare workers, Guangzhou, China. Emerg Infect Dis 2005;11:89–94.
2 Treibel TA, Mainuty C, Burton M, et al. COVID-19: PCR screening of asymptomatic health-care workers at London Hospital. Lancet 2020;395:1608–10.
3 Hunter E, Price DA, Murphy E, et al. First experience of COVID-19 screening of health-care workers in England. Lancet 2020;395:e77–8.
4 Zhao J, Yuan Q, Wang H, et al. Antibody responses to SARS-CoV-2 in patients of novel coronavirus disease 2019. Clin Infect Dis 2020. doi:10.1093/cid/ciaa344. [Epub ahead of print: 28 Mar 2020].
5 Hains DS, Schwaderer AL, Carroll AE, et al. Asymptomatic seroconversion of immunoglobulins to SARS-CoV-2 in a pediatric dialysis unit. JAMA 2020. doi:10.1001/jama.2020.8438. [Epub ahead of print: 14 May 2020].
6 Bosworth A, Whalley C, Poxon C, et al. Rapid implementation and validation of a cold-chain free SARS-CoV-2 diagnostic testing workflow to support surge capacity. J Clin Virol 2020;128:104469.
7 Watanabe Y, Allen JD, Wrapp D, et al. Site-specific glycan analysis of the SARS-CoV-2 spike. Science 2020;369:eaba9883.
8 Wrapp D, Wang N, Corbett KS, et al. Cryo-EM structure of the 2019-nCoV spike in the prefusion conformation. Science 2020;367:1260–3.
9 Ministry of housing, communities and local government, English indices of deprivation 2019.
10 Wang W, Xu Y, Gar R, et al. Detection of SARS-CoV-2 in different types of clinical specimens. JAMA 2020;323:1843–4.
11 Public Health England. Sero-surveillance of COVID-19, Weekly coronavirus disease 2019 (COVID-19) surveillance report, week 22, 2020.
12 Houllihan C, Vora N, Byrne T, et al. SARS-CoV-2 virus and antibodies in front-line health care workers in an acute hospital in London: preliminary results from a longitudinal study, medRxiv 2020.
13 Eyre DW, Luntley SF, D’Onofrio D, et al. Differential occupational risks to healthcare workers from SARS-CoV-2: a prospective observational study, medRxiv 2020.
14 Ip M, Chan PKS, Lee N, et al. Seroprevalence of antibody to severe acute respiratory syndrome (SARS)-associated coronavirus among health care workers in SARS and non-SARS medical wards. Clin Infect Dis 2004;38:e116–8.
15 Williamson EM, Walker AJ, Bhaskaran K, et al. OpenSAFELY: factors associated with COVID-19 death in 17 million patients. Nature 2020.
16 Black JRM, Bailey C, Przewrocka J, et al. COVID-19: the case for health-care worker screening to prevent Hospital transmission. Lancet 2020;395:1418–20.