Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

without the means to manufacture the device have been supported through charities supplying devices and circuits. We encouraged engagement of local health-care teams and provided clear guidance about oxygen supply needs, necessary infrastructure, protective personal equipment, and clinical training. Ongoing support is provided by technical, manufacturing, clinical, and regulatory teams, with assistance from the MHRA. Training materials have been translated into relevant languages, a Facebook group has been established to connect manufacturers in different countries, and webinars are held for manufacturers and clinicians. We have liaised with the WHO, World Bank, overseas governments, and UK governmental departments to encourage a coordinated approach.

The Ventura initiative, translating a brainstorming session into 10 000 devices within 1 month, would not have been possible without the cooperation, dedication, and generosity of individuals, universities, hospitals, companies, governmental bodies, and the media. It shows how usual barriers and procrastinations can be overcome safely and effectively in a time of crisis with a focused, multidisciplinary, agile, and coordinated approach, and a common aim to deliver at pace a device that will hopefully save lives.

The health-care industry can learn some valuable lessons from the motorsports industry in terms of their ability to adapt to ever-evolving situations, their design and manufacturing processes, and their nimble logistic capabilities. Efficient, streamlined, and synergistic partnerships between industry, academia, and health care are needed to break down barriers to innovation and adoption of novel, effective technologies. Worryingly, severe economic recession could further endanger the ability of universities and health care to progress with similar innovative projects. The shrinking UK manufacturing base presents challenges in securing locally sourced parts and product development. Steps should be taken to reduce the heavy reliance on overseas manufacturers who might not be able to deliver during a worldwide crisis. Conversely, developed countries placing trade embargoes on health-care products will help local populations to the detriment of low-income countries. More effort must be made to take collective responsibility for global health.

We are hugely indebted to the many individuals, organisations, and companies who provided support during this project. Neil McGuire (MHRA) merits particular mention. MS reports grants from NewB, Defence Science and Technology Laboratory, Critical Pressure, and Apollo Therapeutics, and fees paid to his research fund from Amormed, Baxter, Biotest, General Electric, New B, Roche, Bayer, and Shionogi, outside of the submitted work. RS reports personal fees from the Royal National Orthopaedic Trust, outside of the submitted work. DL reports personal fees, grants, and non-financial support from GlaxoSmithKline, and personal fees from Griffols outside of the submitted work. All other authors declare no competing interests.

*Mervyn Singer, Rebecca Shipley, Tim Baker, Andy Cowell, David Brealey, David Lomas
m.singer@ucl.ac.uk

Bloomsbury Institute of Intensive Care Medicine, Division of Medicine, UCL, London WC1E 6BT, UK (MS, DB); Intensive Care Unit, UCL Hospitals NHS Foundation Trust, London, UK (MS, DB); NIHR University College London Hospitals Biomedical Research Centre, London, UK (MS, DB, DL); UCL Institute of Healthcare Engineering, London, UK (RS); UCL Mechanical Engineering, London, UK (RS, TB); Mercedes AMG HPP, Brixworth, Northants, UK (AC); Office of the Vice Provost (Health), UCL, London, UK (DL)

Pooled saliva samples for COVID-19 surveillance programme

Published **Online** September 22, 2020 https://doi.org/10.1016/S2213-2600(20)30444-6

See **Editorial** page 1061

For the **data from Anne Wyllie and colleagues** see *N Engl J Med* 2020; published online Aug 28. https://www.nejm.org/doi/full/10.1056/NEJMc2016359

For the **published protocol** see https://wwwprotocolsio/view/salivadirect-rna-extraction-free-sars-cov-2-diagno-bkjgkujw

For more on **pooling of samples for testing for SARS-CoV-2** see **Articles** *Lancet Infect Dis* 2020; published online April 28. https://doi.org/10.1016/S1473-3099(20)30362-5

Health-care staff are at increased risk of COVID-19, thus putting themselves, their families, and their patients at risk. This increased risk negatively affects patient and staff mortality and morbidity (physical and mental). Furthermore, the need to isolate if either infected or exposed to severe acute respiratory syndrome coronavirus disease 2 (SARS-CoV-2) limits the ability of the UK NHS to deliver care when staff are absent from work. This potentially represents one of the biggest threats to providing timely health care as the second wave of SARS-CoV-2 infection develops. Locally, approximately one fifth of our patient-facing respiratory physicians were infected during the first COVID-19 surge in the UK (March–July, 2020), and one third have had to isolate with symptoms or symptomatic contacts at least once. Local ward-based outbreaks have also occurred. Hence, there is a clear need for a robust COVID-19 surveillance system for NHS staff, enabling both staff and patients to have confidence that the risk of workplace nosocomial infection is as low as it can be.

The standard diagnosis for COVID-19 has been based on RT-PCR of a nasopharyngeal swab. However, this method has limitations, including a degree of discomfort for the patient, the need for close contact by a health-care professional for a procedure that can result in coughing and aerosol generation, operator variation in technique, and the requirement for a large supply of swab testing kits. Consequently, the test cannot be easily scaled up to the point where health-care workers can be tested regularly in an affordable, convenient manner.

On Aug 28, 2020, Anne Wyllie and colleagues published data demonstrating that saliva is as sensitive for diagnosing COVID-19 as nasopharyngeal swabs. They studied a population of 70 hospital in-patients

who had tested positive for SARS-CoV-2 infection by nasopharyngeal swab and compared two different methods of diagnosing SARS-CoV-2 infection; saliva samples collected by the patient and a second nasopharyngeal swab taken by health-care workers at the same timepoint. The results demonstrated that 1–5 days after the initial COVID-19 diagnosis, 81% of saliva samples were positive compared with 71% of the nasopharyngeal samples. The authors concluded that "saliva specimens and nasopharyngeal swab specimens have at least similar sensitivity in the detection of SARS-CoV-2 during the course of hospitalisation". The group then repeated the comparison of saliva with nasopharyngeal swabs in 495 asymptomatic health-care workers. Of the 13 individuals with a positive RT-qPCR result from their saliva, nine had collected their own matched nasopharyngeal swabs, of which seven (78%) tested negative. The authors published their methodology for research purposes, which has now received emergency approval from the US Food and Drug Administration.

Our interpretation of these data is that sampling saliva could be as good as, if not better, than nasopharyngeal swabs in diagnosing COVID-19. Although the usual caveat about replicating these data in different populations still applies, especially with regard to sample integrity the further the sampling is taken from the testing laboratory, these data do increase the options available for COVID-19 screening in larger populations. However, in the UK, and probably elsewhere, there are continuing logistical problems with COVID-19 diagnostic capacity. It is not currently possible to deliver the large scale, regular testing with a fast turnaround time, needed for an NHS staff COVID-19 surveillance programme.

One solution is sample pooling. The amplification of the COVID-19 signal by PCR makes the assay very sensitive to low levels of virus and hence allows a number of samples to be pooled and tested in one assay. This method opens the possibility of testing a community at a lower financial and resource cost. If the pooled sample is negative, then it is likely all individuals are negative and no further testing is needed. Similar to all COVID-19-related research, the field is in its infancy; however, pooling techniques are already used to sample untreated human waste-water for SARS-CoV-2 infection in communities, and in this setting the assay might have the sensitivity to detect a positive COVID-19 case of one person in a population of 10 000 people.

Combining saliva sampling with pooling where concerns exist about the second wave of SARS-CoV-2 infection could allow the development of a very efficient, relatively cheap surveillance system. We propose the following system that can be subsequently piloted, analysed, and refined as the evidence base develops. The system uses saliva sampling, pooling, and an additional insight from the world of drug testing in sports—where two samples are taken, but initially only one is analysed.

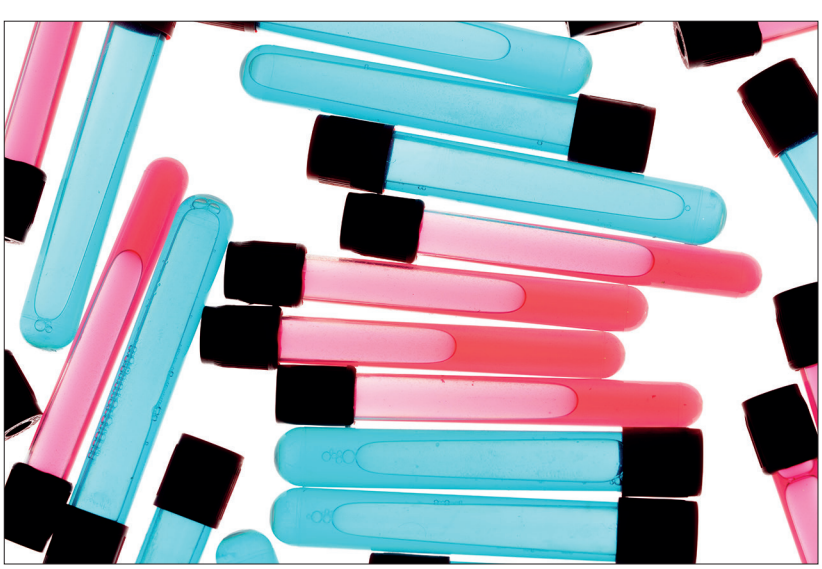
All health-care staff who are in contact with patients provide two saliva samples at least once a week. These are labelled Sample A and Sample B. Sample A is pooled with other samples and the combined pooled sample is tested. If the pooled sample tests positive for SARS-CoV-2, then the constituent individual Sample Bs in that pool are then tested to determine who provided the positive sample. Initial evidence suggests that up to 32 samples can be pooled.

If effective, the saliva surveillance system has the potential to be rapidly scaled to all staff in an NHS Trust at a relatively low cost. The pooling could be done at the level of a ward, medical speciality, social bubble, or group of colleagues. It has potential for use in other settings, such as pre-operative screening, schools and universities, prisons, nursing homes, primary care, and large workplaces. It could also be used for other infections, including influenza surveillance.

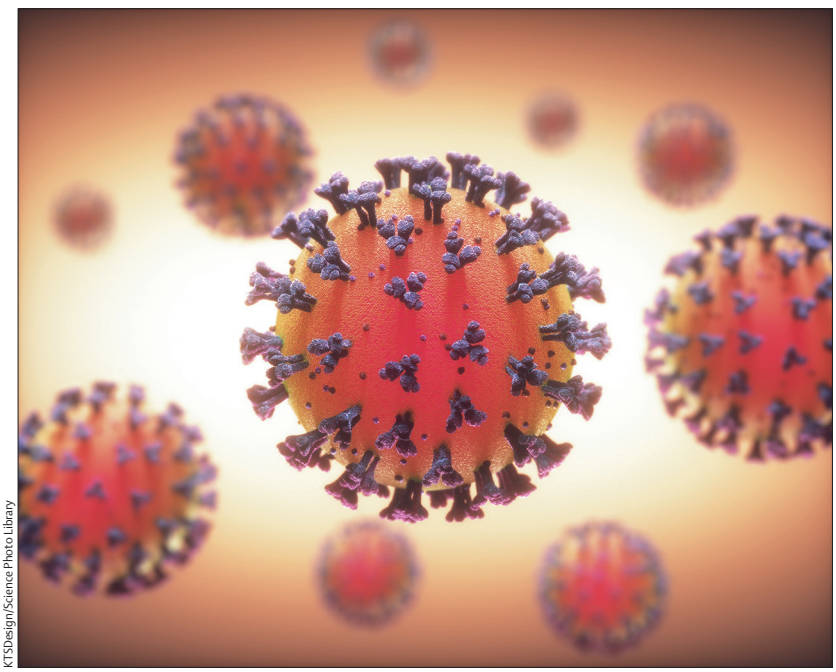
In early September, 2020, the UK Government proposed an ambitious plan for the general population to have access to a surveillance programme for SARS-CoV-2 infection by spring 2021. However, it is unclear if this programme is deliverable within this time frame. Combining the use of self-collected saliva sampling with pooling of the samples does represent a potentially scientifically and economically viable alternative that uses existing laboratory diagnostic resources efficiently. We suggest that this approach is piloted in health-care workers and scaled up rapidly if shown to be effective. It can then be extended to settings external to the hospitals, prioritising primary care settings and nursing home staff and residents.

For the **study on sewage monitoring** see *BMJ* 2020; **370:** m2599

For more on **optimum pool size for pooled SARS-CoV-2 testing see** *Int J Infect Dis* 2020; published online Aug 28. DOI:10.1016/j.ijid.2020.08.063



Wladimir Bulgar/Science Photo Library



KTSDesign/Science Photo Library

This surveillance system does have challenges. There is a risk of detecting prolonged non-viable viral shedding and a risk of contamination (both in pre-analytical and analytical steps) when handling large numbers of saliva samples in the laboratory. Both the cycle threshold and number of samples that should constitute a pool need to be established because pooling efficiency will depend upon both pool size and COVID-19 prevalence. These metrics can be established concurrently, by taking a third and fourth saliva sample, or using nasopharyngeal swabs rather than Sample B. This approach would generate empirical data alongside a pragmatic health-care surveillance programme, complementing and informing theoretical modelling of this approach, for which optimum pool size formulae are now available.

Having worked through the first wave of the COVID-19 pandemic as both front-line clinicians and medical managers, we have observed that in unprecedented times our health-care system needs decision makers to quickly decide, and act on, the point where the balance between pragmatism and evidence lies. A pooled sample approach might not be ideal, but is preferable to waiting for more data, or in this case a population-based surveillance system, which might not deliver in the timescale required.

In our opinion, the potential benefits of a pooled two sample saliva-based surveillance system for COVID-19 outweigh any negatives and this approach should be trialled.

We declare no competing interests.

*Andrew Fogarty, Amelia Joseph, *Dominick Shaw*
dominic.shaw@nottingham.ac.uk

Nottingham NIHR Respiratory Biomedical Research Centre, University of Nottingham, Nottingham NG5 1PB, UK (AF, DS); and Nottingham University Hospitals NHS Trust, Nottingham, UK (AJ)