Modified full-face snorkel mask: answer to the PPE crisis?

Harshul D Measuria, Yash V Verma, Ryan Kerstein, Sarah Tucker

INTRODUCTION
The COVID-19 pandemic has brought to light shortages in personal protective equipment (PPE) preparations and supply across the UK. In an emergency, we have all had to adapt to new living and working conditions. As the government moves to relax the lockdown and recommend the use of masks to be worn by the general public, supply problems are likely to continue, hindering the health service.

There is a definite shortage in supply and clinicians are understandably concerned about this. Two surveys undertaken by the Royal College of Surgeons of 2000 of their members highlighted that over a third of surgeons felt that their Trust did not have adequate PPE, particularly FFP3 masks and full-face visors. Over a quarter of surgeons were not confident that the supplied PPE had been adequately fit tested, with several hospitals around the country removing fit testing altogether instead adopting the fit check alone. Alongside this, 15% felt under pressure to undertake procedures without adequate PPE. BBC Panorama highlighted a worrying lack of preparation from the government in case of a pandemic. Given that this is the starting point for our healthcare system, what has been developed to combat the issue?

METHODS
Adaptation of a commercially available full-face snorkel mask has been raised as a possible solution. As a concept, it would appear a good idea-made of materials that would allow reuse, provides both eye and airway protection and requires only a simple modification to allow connection of a heat and moisture exchange filter by way of traditional manufacturing by moulding, or quicker still, by 3D printing.

In essence, this simple change could create a reusable piece of respiratory and eye protecting personal protective equipment (PPE) that could be readily available for masks used for aerosol-generating procedures, eye and hearing protection against which PPE made available at low cost and rapid production.

What are the new findings?

- A commercially available full-face snorkel mask can be modified to create a variety of respiratory assisting devices.
- Combining a connector piece and a heat and moisture exchange filter to a full-face snorkel mask can create a reusable piece of respiratory and eye protecting personal protective equipment (PPE).
- Challenges to overcome using this system include carbon dioxide clearance, satisfactory fit and certification testing.
- Additional challenges such as cleaning regimes and unfiltered exhaled air still need to be tackled.

How might it impact on healthcare in the future?

- In an emergency crisis situation, however, this adaptation could prove to be an easily accessible solution for all to have level 2 PPE.
RESULTS

As part of the safety testing of these masks, a quantitative fit test is the gold standard that needs to be passed. Most hospitals will have easy access to qualitative fit testing as is required for FFP3 seal-efficacy testing. However, passing a qualitative fit test for a full-face mask does not make it safe for the user. Despite a successful qualitative fit test suggesting a good seal and protection from inhaling viral particles, the quantitative fit testing of these modified PPE devices has identified a concerning level of carbon dioxide build-up within the mask.8

Since this initial finding, different teams have come together across the globe to reassess the science behind this modification with a collaborate team of medics and engineers at Stanford University having successfully designed a modification to the snorkel mask that satisfactorily passes the quantitative testing (figure 1B). SEAC of Italy has managed to go one step further and has successfully achieved a Conformité Européenne (CE) certification of their adapted snorkel mask for use as PPE (figure 1A).

On the strength of this evidence, the Czech Republic has repurposed 25 000 snorkel masks to be given to those who needed it most as a reusable method of PPE.9 Figure 1 shows the different masks that have been verified to be safe for use in their alternative form.

DISCUSSION

These models that have been successfully adapted to be safe for use have identified a number of key design similarities which contribute to their success. These include

► Single filtered inflow port.
► Outflow ports to remain separate channels ensuring no mixing of inspired and expired gases.
► Maintenance of one-way exhalation valve.
► Standard ISO 22 mm port to attach heat and moisture exchange filter to the connector piece.
► Inert 3D printing material (Formlabs high temperature resin/polylactic).

These designs should ensure that the filter will protect from COVID-19, but the remainder of the system will be safe for the user without risking hypercapnia.

A safe, reusable mask would also require an equally safe cleaning regime. Although one has not been formalised, suggestions have included wiping with 70% ethanol wipes in between uses with submersion in a 50 ppm chlorine solution at the end of the day.7 Any reusable option will need a suitably verified cleaning regime to ensure safety of the end user.

The full-face snorkel mask adaptation is reliant on a one-way exhalation valve to facilitate adequate carbon dioxide clearance. Unfortunately, this remains the site of unfiltered exhaled air being expelled. Being a product of personal protection and not patient protection, no current unpowered reusable PPE face mask is able to fulfil both roles. Raising the issue of powered respirators then calls into question issues of supply again and hence is not necessarily a suitable solution in times of supply crises.

Despite the work that is involved, innovators should not be discouraged by these hurdles. Several studies quoted figures between 28% and 85%11 12 of subjects failing quantitative fit testing with a single respirator model, while others quoted close to 28% failing three different respirators offered.13 In a study published following the H1N1 pandemic in 2009, nearly 59% of subjects labelled the available respirators as intolerable and non-wearable for extended periods of time.14 Nearly a decade on, there is not only a shortage during the ongoing pandemic but also a need for a better respirator overall.

CONCLUSION

The reality, therefore, is that there is no one-size-fits-all mask. Innovations around this area should be encouraged and collaboration between engineers, clinicians
and regulators should be encouraged. Together, a suitably safe solution could be created to a problem that is not likely to disappear anytime soon.

Acknowledgements Heartfelt thanks to all those who supported this venture but wished to remain anonymous. It would have not been possible without your technical support and expert advice.

Contributors HDM and YVV carried out the project and wrote the original article. RK was also involved in conducting the project and acted as editor for the article. ST came up with the original idea of the project, brought together the team and conducted the project.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests A team of authors in Oxford are attempting to pursue a similar adaptation to help with the aforementioned personal protective equipment (PPE) shortages. They have been performing the necessary fit testing and have submitted an option to an independent notification body for the necessary extensive testing in order to be certified as PPE and cleared for safe clinical use. The authors do not recommend its use prior to getting said certifications and write this correspondence purely for informative purposes.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

This article is made freely available for use in accordance with BMJ’s website terms and conditions for the duration of the COVID-19 pandemic or until otherwise determined by BMJ. You may use, download and print the article for any lawful, non-commercial purpose (including text and data mining) provided that all copyright notices and trade marks are retained.

REFERENCES
1 UK Government. Our plan to rebuild: The UK Government’s COVID-19 recovery strategy. London: Government Publications, 2020.
2 Royal College of Surgeons. Report of survey findings: PPE and testing during the COVID-19 pandemic. London: Royal College of Surgeons Publication, 2020.
3 Davies H, Pegg D, Lawrence F. Revealed: value of UK pandemic stockpile fell by 40% in six years. The Guardian, 2020. Available: https://www.theguardian.com/world/2020/apr/12/revealed-value-of-uk-pandemic-stockpile-fell-by-40-in-six-years [Accessed 13 May 2020].
4 Elkington P, Morgan H. Personal respirators for population level control of the COVID19 pandemic. J Infect 2020;81:318–56.
5 Pearson SD, Hall JB, Parker WF. Two for one with split- or co- ventilation at the peak of the COVID-19 tsunami: is there any role for communal care when the resources for personalised medicine are exhausted? Thorax 2020;75:444–5.
6 Isinnova. ISI 3D - 4 The Future - 3D Printing Towards the Future. Available: https://www.isinnova.it/easy-covid19-eng/ [Accessed 30 Apr 2020].
7 Kroo L, Kothari A, Hannebelle M, et al. Pneumask: modified Full-Face snorkel masks reusable personal protective equipment for hospital personnel. medRxiv 2020.
8 Greig PR, Carvalho C, El-Boghdady K, et al. Safety testing improvised COVID-19 personal protective equipment based on a modified full-face snorkel mask. Anaesthesia 2020;75:970–1.
9 Pandemija. Resporator Projects Around the World [online], 2020. Available: https://www.pandemija.info/related-projects/?fbclid=IwAR1Jkq2IG_zz9ikd7c5FwTodbDrc92vEBp4nHwXwjFk7oYanXQaIj81dY [Accessed 30 Apr 2020].
10 Instituto Italiano Di Tecnologia. SEAC protective mask [online], 2020. Available: https://www.iit.it/iit-vs-covid-19/seac-protective-mask [Accessed 18 May 2020].
11 Lee MC, Takaya S, Long R, et al. Respirator-fit testing: does it ensure the protection of healthcare workers against respirable particles carrying pathogens? Infect Control Hosp Epidemiol 2008;29:1149–56.
12 Spies A, Wilson KS, Ferrie R. Respirator fit of a medium mask on a group of South Africans: a cross-sectional study. Environ Health 2011;10:17.
13 Winter S, Thomas JH, Stephens DR, et al. Particulate face masks for protection against airborne pathogens - one size does not fit all: an observational study. Crit Care Resusc 2010;12:24–7.
14 Hospital Employee Health. In search of the perfect HC respirator [online], 2020. Available: https://www.reliasmedia.com/articles/18253-in-search-of-the-perfect-hc-respirator [Accessed 30 Apr 2020].