Discrepancy between S_pO_2 and S_aO_2 in patients with COVID-19

In patients admitted to our critical care unit during the COVID-19 pandemic, we observed that oxygen saturation measured by pulse oximetry (S_pO_2) was consistently lower than arterial oxygen saturation (S_aO_2) measured directly by blood gas analysis.

Over 2 days, S_pO_2 and corresponding S_aO_2 were recorded from patients with severe COVID-19 (n = 17). The S_pO_2 was measured using a NellcorTM (Medtronic, Watford, UK) reusable sensor. The GEM Premier 5000 gas analyser (Instrumentation Laboratory, Werfen, Germany) was used to directly measure S_aO_2.

Peripheral oxygen saturation underestimated S_aO_2 by > 3% in 15 patients. In nine patients, this gap was > 5%. A Bland-Altman analysis suggested S_pO_2 consistently under-read S_aO_2 by an average of 5.3% with 95% limits of agreement. However, our small sample size could be prone to bias, and we did not have a matched control group.

Pulse oximetry is a simple, cheap and non-invasive method of measuring S_pO_2. The pulse oximeter consists of two light-emitting diodes which transmit light at two wavelengths; 660 nm and 940 nm, and a photodetector that is sited across a tissue bed, for example, a finger. It is assumed that absorbance at these wavelengths is due to de-oxyhaemoglobin or oxyhaemoglobin [1]. The accuracy of pulse oximeters is generally quoted as ±2%' [1]. In the critically ill, S_pO_2 does not reliably predict equivalent changes in S_aO_2 [2]. This is expected as the original calibration is based on calculations made from employing healthy volunteers. Peripheral oxygen saturation can underestimate S_aO_2 in low perfusion states, arrhythmias, vasoconstriction, venous pulsations, oedema and severe anaemia [2–4]. Nail polish can result in erroneous signal measurement whereas the presence of dyshaemoglobins, or haemoglobin variants can interfere with absorbance [4]. Elevated glycosylated haemoglobin results in an overestimation of S_aO_2 by the S_pO_2 [5]. In sepsis and septic shock, there are conflicting reports on how S_pO_2 is biased [2–4].

In our patients, we were able to confirm good quality of the pulse oximeter trace and known causes for S_pO_2 underestimation [2–4] were excluded. An explanation for our observations remains unclear. Suggested hypotheses may include the following; firstly, high ferritin, d-dimer or other proteins in patients with COVID-19 may have different spectral properties at 660 nm and 940 nm [6]. These proteins may adversely affect the signal-to-noise ratio, thereby reducing the precision of pulse oximetry. Secondly, arteriolar dilatation secondary to tissue hypoxia may lead to venous pulsations, which in turn contributes to falsely low S_pO_2 readings because venous oxyhaemoglobin saturation is also measured in the pulsatile vein [3, 4]. COVID-19 may contribute through microvascular complications to tissue hypoxia. In addition, there is anecdotal evidence that anaerobic respiration due to secondary infection by anaerobic bacteria in COVID-19 might inhibit mitochondrial cytochrome oxidase, thereby causing hypoxia at the cellular level (Chakraborty and Das, unpublished observations, https://osf.io/s48fv/). Finally, a possible formation of a complex between the virus and haemoglobin may result in increased red light absorbance relative to infrared absorbance, thereby resulting in a lower S_pO_2.

Our observations in a relatively small number of patients with COVID-19 pneumonia in critical care suggest that S_pO_2 does not reliably predict S_aO_2, with S_pO_2 consistently underestimating S_aO_2. On our unit, oxygen titration is mostly guided by S_pO_2, and therefore patients may have been administered a higher inspired oxygen fraction than was necessary. It is also possible that the phenomenon of 'happy hypoxia' described in patients with COVID-19 at an earlier stage in their presentation could be explained in part by these observations.

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Measurement of airborne particle exposure during simulated tracheal intubation using various proposed aerosol containment devices during the COVID-19 pandemic

We read with great interest the article by Simpson et al. [1]. We are grateful to the authors for providing the first scientific evaluation on the impact of improvised barrier 'devices' on dispersion of exhaled aerosols. As the authors point out, with the exception of the sealed box with suction, all were found to cause no significant decrease in ambient aerosol particles. In the case of the 'aerosol box', rather worryingly, increases in particle counts were recorded.

These findings are highly concerning given the seemingly widespread use of such devices during aerosol-generating procedures in patients with COVID-19. As we reconcile the duty to care for patients in the face of this highly transmissible and potentially deadly disease, the requirement for healthcare worker protection is an issue of respecting basic human rights as much as their psychological need to reduce anxiety in a highly stressful environment. However human and understandable the fear may be, we cannot forget that our work is first based on science. We can, and should, turn to science for potential solutions.

Based on their findings, we heartily support the decision by Simpson et al. to remove passive barriers from their intubation protocols. We do, however, feel compelled to comment on several aspects of the study.

Excluding the emitted aerosols from ventilation in the room will result in a highly concentrated plume. This will favour aerosol escape via apertures on the rigid box at times of sudden increases in internal pressure. This phenomenon in the Simpson et al. experiments was likely facilitated by the conditions of negative pressure room ventilation [1]. Here, it becomes necessary to think about what is happening outside the box; airflow in the space around the box becomes crucial to understanding the pathways of dispersion and areas of the greatest exposure.

The authors positioned the particle counter based on the presumed relevance to laryngoscopists' exposure and recorded the changes in aerosol counts. However, there may have been nearby locations with even higher counts, including those relevant to the assistant, as was alluded to in the manuscript. Conversely, a particle counter located in another position might not have picked up any spikes at all.

To avoid trial and error in selecting optimal sampling locations, computational fluid dynamic modelling simulation of the particular room with the appropriately set boundary conditions can be performed [2]. A relatively minor change in position of the particle counter with respect to the room airflow patterns could lead to a significant degree of variation in aerosol dispersion and particle counts. Controlling for the variability of airflow, in addition to humidity and room temperature, may be difficult but is necessary to achieve results that truly reflect the effect of the barrier. We wonder how different the results would be if the experiments were done in a 'positive pressure room', a type of ventilation that is present in most operating theatres. In addition, the position of the laryngoscopist (and the point of origin and direction of flow of their exhaled breath) is dictated by the ergonomic properties of each device. Given that participants wore simple procedure masks, unaccounted for variations in airflow and possible droplet contamination due to their breathing were likely introduced.

The finding that the five micron particles were more likely to be sampled outside the aerosol box and the sealed box was puzzling. At the high end of the size spectrum for aerosols, these relatively large particles are likely to settle rapidly. Depending on the exact conditions during baseline measurements, the location of sampling and possible environmental contamination may have contributed to this finding.

Lastly, the most interesting result from the problem-solving perspective is related to the performance of the sealed box with suction. By virtue of its construction, the box

