

Finally, we would like a little more detail on how reference coughs were measured because it is not clear how confident readers can be that the reference coughs are generalisable. For example, if they were simply measured as a sequential cough over a short period of time, there may be concerns that the airway could dry out with each subsequent effort, affecting the average calculation.

The findings of Brown et al. [1] are important and highly relevant, but we do have reservations related to how generalisable the findings are to other clinical settings or patient populations. Balancing infection prevention and theatre throughput will be critical in managing a second surge of the COVID-19 pandemic. These data inform that debate, but we are not certain that they definitively demonstrate that aerosol precautions are no longer required when managing COVID-positive patients during airway manipulation.

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Reference

1. Brown J, Gregson FKA, Shrimpton A, et al. A quantitative evaluation of aerosol generation during tracheal intubation and extubation. *Anaesthesia* 2021; **76**: 174–81.

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A quantitative evaluation of aerosol generation during tracheal intubation and extubation

We read with great interest the article by Brown et al. [1]. It posits that tracheal intubation and extubation should not be considered high-risk aerosol-producing procedures.

We agree that with effective neuromuscular blockade during rapid sequence induction, tracheal intubation is unlikely to produce a large number of infectious aerosols. This study also included a small number of patients who required repeated attempts at intubation. These patients still produced a low number of aerosols suggesting that, even with prolonged airway instrumentation time, appropriate tracheal intubating conditions minimise the risk of aerosol production. The lack of aerosol generation during facemask ventilation is surprising and may be related to the patient population studied. In practice, the majority of critically ill COVID-19 patients requiring tracheal intubation are likely to be obese and challenging to adequately mask ventilate. For these patients, if we presume there will be more leakage around the facemask seal, the degree of aerosol generation is likely to be increased as well.

The authors note some of the study limitations, specifically that the reference cough used was one of the investigators, and that none of the subjects were COVID-19 positive. A better control would be to take the average of volitional coughs from several individuals. It seems reasonable to assume that patients with

respiratory symptoms of COVID-19 would also have a higher propensity to cough forcefully. Based on the small reference sample (14 tracheal extubations), we cannot assume that coughs during tracheal extubation generate fewer aerosols than volitional coughs. As the authors point out, the use of a sampling funnel can be limiting and does not fully encapsulate the aerosol cloud nature of dispersion.

The operating theatre utilised in their study has a very high air exchange rate with 500–650 air changes per hour. This far exceeds the Centers for Disease Control and Prevention recommendations of 15 air changes per hour and 12 for negative pressure rooms [2]. The authors state that they considered the effect of laminar flow on the observations by testing measurements with ventilation on and off, and did not notice any difference in particle measurement during coughing and tracheal intubation. However, they maintained high laminar flow rates during all tracheal extubations for pragmatic reasons. Aerosol particles generally follow airflow patterns imposed by ventilation, so it stands to reason that in settings without the same availability of ultraclean theatre ventilation air supply rates, particle measurements will be much higher [3].

Based on the above concerns, we believe that broad recommendations to relax personal protective equipment

standards, continue elective surgery in the event of a second wave, and reduce our level of vigilance, would be premature at this juncture.

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References

1. Brown J, Gregson FKA, Shrimpton A, et al. A quantitative evaluation of aerosol generation during tracheal intubation and extubation. *Anaesthesia* 2021; **76**: 174–81.
2. Centers for Disease Control and Prevention. Appendix B. Air. Airborne Contaminant Removal – Table B.1. Air changes/hour (ACH) and time required for airborne-contaminant removal by efficiency. <https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html#tableb1> (accessed September 2020).
3. Bourouiba L. Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19. *Journal of the American Medical Association* 2020; **323**: 1837–8.

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A quantitative evaluation of aerosol generation during tracheal intubation and extubation: a reply

We thank all the authors [1–3] for their interest in our study [4]. We have debated some of these issues in a recent *Anaesthesia* podcast (www.podbean.com/ew/pb-sm9g3-f0d570) but address the others herein. Our ethical permission enabled us to conduct environmental monitoring during patient care but not to modify the conduct of anaesthesia nor document the characteristics of the patients beyond noting the urgency and type of surgery. In future interventional work, we aim to analyse some of the patient level factors mentioned by Drs Schumacher and Greig [1].

Use of a cough as a reference provided standardisation across monitoring sessions and enabled the aerosol production during intubation and extubation to be put into a meaningful context. We used the average aerosol produced by a cough from a single investigator (JB), measured in sets of three at 1-min intervals under identical conditions as for patient recordings (Fig. 1 and twitter.com/i/status/1318890563303804928). Aerosol generation did not depend on cough sequence in a set (Fig. 1a) and comparing JB's cough to other healthy volunteers indicated he was not an outlier. We agree with Drs Wong and Abramowicz [2] that using the patients' own cough as the reference may be beneficial and are doing that in our current studies. We also agree that coughs from patients with COVID-19 may produce more aerosol, but this remains to be quantitatively verified.

We found no evidence of aerosol generation during facemask ventilation as part of the intubation sequence (twitter.com/i/status/1319171324401668099). Of note, facemask ventilation was undertaken by anaesthetists of

varying degrees of experience and it is likely some leak occurred, yet no aerosol was detected during our measurement. The hypothesised cause of bio-aerosol during facemask ventilation is opening/closing of terminal bronchioles, turbulence at the glottic inlet or high velocity airflow across mucosal surfaces [5]: it is plausible the bronchiole opening-closing cycles may be lessened by positive pressure ventilation [6] and the airflow velocities with manual ventilation are notably lower than during a cough, or even normal breathing. All these factors would tend to reduce, rather than increase, aerosol generation. Dhillon et al. [7] documented aerosol generation with facemask ventilation using quite comparable methodology, a difference which we cannot yet explain. In their study, aerosol generation occurred throughout the period of facemask ventilation which is puzzling if the anaesthetists did maintain a patent airway with a good facemask seal. To resolve this uncertainty, we are undertaking further studies using a protocol agreed with the Melbourne group.

We studied 10 tracheal extubations with the collecting funnel positioned perpendicular to the mouth and 0.5 m distant. In a further four tracheal extubations, the collecting funnel was moved approximately 45° to the perpendicular above and behind the patient's head, to where the anaesthetist normally positions themselves. In this funnel position, the aerosol generated when the patient coughed during tracheal extubation was not detected, reflecting the directionality of the aerosol emission. While extubation coughs are typically weaker than a volitional cough, and this might be anticipated because of the residual effects of anaesthetic agents, the