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COVID-19 CORRESPONDENCE

Effects of combined oxygen and surgical masks on inspired fraction of oxygen: relevance to COVID-19-induced respiratory failure

Satoshi Hamada[1], Naoya Tanabe[2,*] and Toyohiro Hirai[2]

[1]Department of Advanced Medicine for Respiratory Failure, Graduate School of Medicine, Kyoto University, Kyoto, Japan and [2]Department of Respiratory Medicine, Graduate School of Medicine, Kyoto University, Kyoto, Japan

*Corresponding author. E-mail: ntana@kuhp.kyoto-u.ac.jp

Keywords: acute hypoxaemic respiratory failure; COVID-19; inspired oxygen concentration; oxygen therapy; surgical mask

Editor—On March 11, 2020, WHO declared the novel coronavirus disease 2019 (COVID-19) outbreak a global pandemic.[1] Some patients with COVID-19 present with acute hypoxaemic respiratory failure. In such cases, low-flow oxygen therapy through a nasal cannula or an oxygen mask and high-flow nasal cannula oxygen therapy are initially used for supportive oxygen therapy before determining the need for invasive mechanical ventilation.[2]

Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), the causative agent of COVID-19, can be transmitted by aerosol inhalation or contact with fomites.[3] The risk of aerosol transmission has been the largest concern among healthcare workers who care for patients with COVID-19 and acute hypoxaemic respiratory failure. The use of a surgical mask is recommended for patients receiving supportive oxygen therapy.[4] Although placement of a surgical mask over nasal cannulae is the standard, it remains unclear whether a surgical mask should be placed over or under an oxygen mask. In particular, the effect of the surgical mask position relative to the oxygen mask on fraction of inspired oxygen (F_IO_2) remains to be established. This present study was an experimental trial to evaluate the effect of surgical mask placement over or under an oxygen mask on F_IO_2 according to oxygen flow rate.

The experimental trial was performed using INOflo® DS (Mallinckrodt Pharmaceuticals, Hampton, NJ, USA), which enabled continuous monitoring of F_IO_2 changes in a patient gas sample line that drew air at a flow rate of 230 ml min^{-1}. We measured F_IO_2 around the lips through the mouth under normal breathing conditions in five healthy volunteers in three situations: (1) oxygen mask (EcoLite™; Intersurgical, Wokingham, UK) without a surgical mask (Supplementary Fig. S1a); (2) oxygen mask over a surgical mask (Supplementary Fig. S1b); or (3) oxygen mask under a surgical mask (Supplementary Fig. S1c). Oxygen flow rates were set at 5 L min^{-1} (low), 7 L min^{-1} (moderate), or 10 L min^{-1} (high). We collected data on F_IO_2, which reached a plateau around 1 min after changing to each condition. Written informed consent was obtained from all participants.

Data are expressed as a median (inter-quartile range). All statistical analyses were performed using JMP Pro 14 software (SAS Institute, Cary, NC, USA). For multiple comparisons, the Kruskal–Wallis test followed by the *post hoc* Steel–Dwass test was used. Differences were considered statistically significant at $P<0.05$.

The five volunteers, aged 29–44 yr, had a median ventilatory frequency of 15 (13–17) bpm. As shown in Supplementary Table S1 and Figure 1, F_IO_2 was higher when wearing an oxygen mask under a surgical mask than when wearing an oxygen mask without a surgical mask and when wearing an oxygen mask over a surgical mask, regardless of oxygen flow rate. At a flow rate of 5 L min^{-1}, F_IO_2 was higher when wearing an oxygen mask without a surgical mask than when wearing an oxygen mask over a surgical mask (P=0.031) (Supplementary Table S1 and Fig. 1a).

This report described two important points. First, at a low oxygen flow rate of 5 L min^{-1}, F_IO_2 decreased when wearing an oxygen mask over a surgical mask compared with wearing an oxygen mask without a surgical mask. However, a surgical mask needs to be placed under an oxygen mask to prevent aerosol transmission to healthcare workers, because it cannot entirely cover an oxygen mask. In this situation, oxygen flow rates have to be adjusted, because the expected F_IO_2 cannot be

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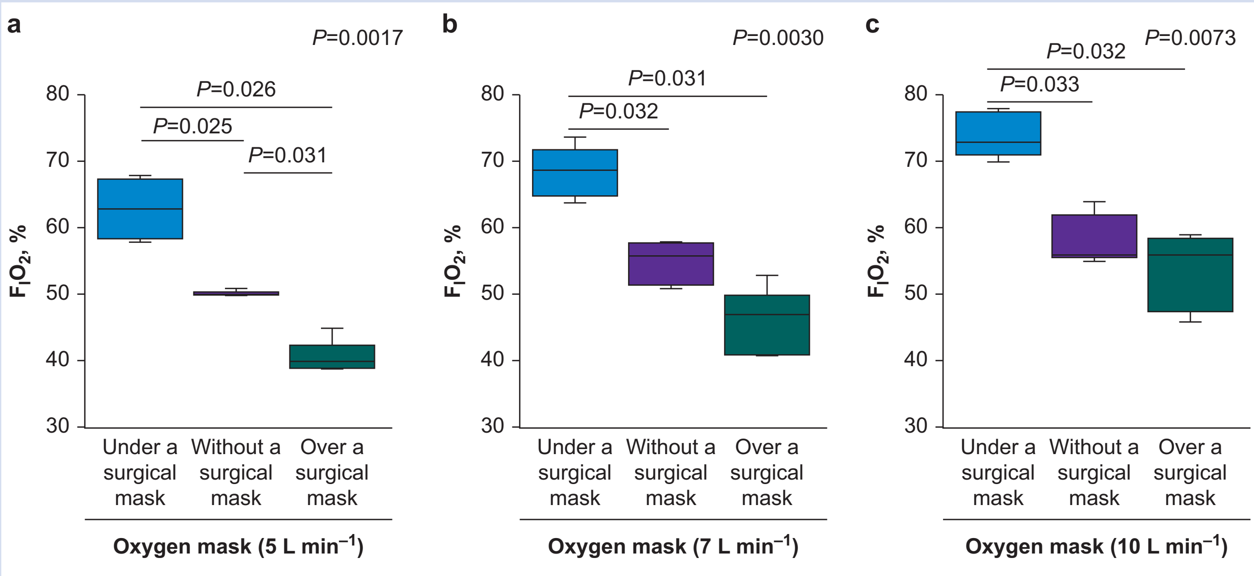

Fig 1. The F_IO_2 measured depending on surgical mask position relative to an oxygen mask. Measurements were made for wearing an oxygen mask over a surgical mask, oxygen mask without a surgical mask, or oxygen mask under a surgical mask at oxygen flow rates of (a) 5 L min^{-1}, (b) 7 L min^{-1}, and (c) 10 L min^{-1}. F_IO_2, fraction of inspired oxygen.

administered. Second, F_IO_2 increased when wearing an oxygen mask under a surgical mask regardless of the oxygen flow rate. In this situation when an unexpectedly higher F_IO_2 can be administered, patients would need to be carefully observed in order to not miss the appropriate timing of intubation, if necessary.

Our results are in line with those of Montiel and colleagues[5] who showed that a surgical mask over a high-flow nasal cannula device improved blood oxygen level in patients with COVID-19. These findings could be explained by a decrease in room air entrainment diluting the gas mixture.[5] In contrast, Binks and colleagues[6] reported that F_IO_2, which was examined using a carbon dioxide sample line attached to a 16 G cannula, did not differ according to the position of the surgical mask relative to a Hudson oxygen mask at a flow rate of 6 L min^{-1}. However, the figure in their report showed significantly higher expiratory oxygen concentrations when wearing an oxygen mask under a surgical mask than when wearing an oxygen mask over a surgical mask. Because different monitoring methods and conditions might yield inconsistent F_IO_2 measurements, direct measurement of blood oxygen levels rather those of F_IO_2 should be considered in further studies to examine the influence of surgical mask position on oxygenation in patients with acute hypoxaemic respiratory failure.

Our study included a small number of participants and was performed under normal respiratory conditions in healthy participants. When using an oxygen mask, F_IO_2 can change with ventilatory frequency and tidal volume.[7] Therefore, future studies with a larger number of participants and under altered respiratory conditions, such as different ventilatory frequencies and tidal volumes, are needed to evaluate the effect of surgical mask position on F_IO_2 when using an oxygen mask.

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Declarations of interest

SH reports grants from Teijin Pharma, outside the submitted work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2021.02.025.

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Recovery after critical illness in COVID-19 ICU survivors

Alexander J. Parker[1,2], Anita Humbir[1], Pooja Tiwary[1], Monalisa Mishra[1], Mohan Shanmugam[3], Kailash Bhatia[3], Alastair Duncan[3], Manu-Priya Sharma[3], Gareth Kitchen[3], Seema Brij[4], Siobhan Wilde[5], Andrew D. Martin[1], Anthony Wilson[1,2] and Craig Brandwood[1,*]

[1]Adult Critical Care Department, Manchester Royal Infirmary, Manchester University NHS Foundation Trust, Manchester, UK, [2]Division of Informatics, Imaging and Data Sciences, School of Health Sciences, Faculty of Biology, Medicine and Health, University of Manchester, Manchester, UK, [3]Directorate of Anaesthesia and Perioperative Medicine, Manchester Royal Infirmary, Manchester University NHS Foundation Trust, Manchester, UK, [4]Department of Respiratory Medicine, Manchester Royal Infirmary, Manchester University NHS Foundation Trust, Manchester, UK and [5]Department of Physiotherapy, Manchester Royal Infirmary, Manchester University NHS Foundation Trust, Manchester, UK

*Corresponding author. E-mail: Craig.Brandwood@mft.nhs.uk

Keywords: acute respiratory distress syndrome; COVID-19; critical care; functional status; outcome; recovery; rehabilitation

Editor—Coronavirus disease 2019 (COVID-19) has placed an enormous strain on ICUs in the UK with mortality rates of about 40%.[1] Invasively ventilated ICU survivors have frequently required prolonged critical care, but to date there have been limited reports on recovery and rehabilitation in these patients. Case series have mainly focused on all hospitalised patients, including patients with less severe disease.[2,3] Studies in critically ill individuals have been limited to functional status assessments or have focused on the residual radiological features in these patients.[4,5]

Our dedicated ICU COVID-19 follow-up clinic has assessed all patients cared for during the first wave of the UK COVID-19 pandemic. We report our findings for invasively ventilated patients from this multidisciplinary assessment of patient recovery and rehabilitation. Our institution's research and innovation department determined that this project did not require ethical approval. Information governance safeguards were approved by our institution's Caldicott guardian.

Face-to-face review was undertaken by a critical care consultant with input from physiotherapists, occupational therapists, dieticians, and critical care nurses. Patients completed quality of life, anxiety, depression, and post-traumatic stress surveys by telephone before review, and chest radiograph, pulmonary function tests, and measures of muscle strength in the clinic. Subjective and objective measures of dyspnoea were recorded.

Between March 17 and May 31, 2020, 110 patients were admitted to our ICU with confirmed or probable COVID pneumonitis: 60/110 (54.5%) were invasively ventilated, of whom 40 (66.7%) survived to ICU discharge and 38 (63.3%) were discharged home. Of these, 36/38 patients (95%) attended the follow-up clinic. Detailed patient characteristics and ICU care can be found in Supplementary Table S1.

Neuromuscular blocking agent (NMBA) infusion was used in 26/36 (72%) patients; 15/36 (42%) required prone positioning; 20/36 (56%) required tracheostomy to facilitate weaning from the ventilator; and 2/36 (6%) required transfer to another unit for extracorporeal membrane oxygenation (ECMO). The median length of stay in our ICU was 25 (inter-quartile range [IQR], 14–34) days. Patients were seen in the clinic 10.9 (standard deviation [SD], 2.4) weeks after hospital discharge. Table 1 provides an overview of the rehabilitation and recovery metrics assessed.

The majority of patients (83%) had complete resolution of their radiographic findings and normal oxygen saturations both at rest and after exertion in a 60-s sit-to-stand test. Pulmonary function tests identified a mild restrictive defect with normal carbon monoxide transfer coefficient (KCO). However, there was a marked reduction in grip strength measurements in comparison with a healthy population reference range of similar age and sex.[6] From a functional perspective, scores were reduced in all Short Form (SF)-36 domains with the