Modified N95 Mask Delivers High Inspired Oxygen Concentrations While Effectively Filtering Aerosolized Microparticles

Alexandra Mardimae, Hon BSc
Marat Slessarev, MSc
Jay Han, Hon BSc
Hiroshi Sasano, MD
Nobuko Sasano, MD, PhD
Takafumi Azami, MD, PhD
Ludwik Fedorko, MD, PhD
Rob Fowler, MD, MSc
Joseph A. Fisher, MD

From the Department of Anesthesiology (Mardimae, Slessarev, Han, Fedorko, Fisher) and Occupational Health and Safety (Savage), University Health Network, Toronto, Ontario, Canada; the Department of Physiology, University of Toronto, Toronto, Ontario, Canada (Mardimae, Slessarev, Han, Fisher); the Department of Anesthesiology and Medical Crisis Management, Nagoya City University Graduate School of Medical Sciences, Nagoya, Japan (H. Sasano, N. Sasano, Azami); and the Interdepartmental Division of Critical Care Medicine, University of Toronto, Sunnybrook and Women’s College Health Sciences Centre, Toronto, Ontario, Canada (Fowler).

Study objective: In a pandemic, hypoxic patients will require an effective oxygen (O₂) delivery mask that protects them from inhaling aerosolized particles produced by others, as well as protecting the health care provider from exposure from the patient. We modified an existing N95 mask to optimize O₂ supplementation while maintaining respiratory isolation.

Methods: An N95 mask was modified to deliver O₂ by inserting a plastic manifold consisting of a 1-way inspiratory valve, an O₂ inlet and a gas reservoir. In a prospective repeated-measures study, we studied 10 healthy volunteers in each of 3 phases, investigating (1) the fractional inspiratory concentrations of O₂ (FIO₂) delivered by the N95 O₂ mask, the Hi-Ox80 O₂ mask, and the nonrebreathing mask during resting ventilation and hyperventilation, each at 3 O₂ flow rates; (2) the ability of the N95 mask, the N95 O₂ mask, and the nonrebreathing mask to filter microparticles from ambient air; and (3) to contain microparticles generated inside the mask.

Results: The FIO₂s (median [range]) delivered by the Hi-Ox80 O₂ mask, the N95 O₂ mask, and the nonrebreathing mask during resting ventilation, at 8 L/minute O₂ flow, were 0.90 (0.79 to 0.96), 0.68 (0.60 to 0.85), and 0.59 (0.52 to 0.68), respectively. During hyperventilation, the FIO₂s of all 3 masks were clinically equivalent. The N95 O₂ mask, but not the nonrebreathing mask, provided the same efficiency of filtration of internal and external particles as the original N95, regardless of O₂ flow into the mask.

Conclusion: An N95 mask can be modified to administer a clinically equivalent FIO₂ to a nonrebreathing mask while maintaining its filtration and isolation capabilities. [Ann Emerg Med. 2006;48:391-399.]

INTRODUCTION

There is worldwide concern about an imminent influenza pandemic. In this event, affected patients will back up in emergency departments (EDs)¹ and ambulances,² placing their staff at increased risk of infection. These considerations highlight the importance of transmission prevention strategies in the protection of ambulance and ED personnel. Currently, their personal protective devices include gloves, gowns, shoe covers, appropriate filter masks, and positive-pressure isolation hoods.³ These barriers are sometimes ineffective because they are overwhelmed by prolonged exposure and large viral loads⁴ or because they are not used properly, in time, or at all.⁵⁻⁷
Editor’s Capsule Summary

What is already known on this topic
We protect health care workers from communicable disease by giving them protective equipment and using devices that decrease emission of infectious agents from the source patient.

What question this study addressed
This study shows that an N95 mask can be modified to deliver oxygen to a person in a manner similar to a nonrebreathing mask while providing significant emissions reduction.

What this study adds to our knowledge
It is possible to practically increase protection for clinicians treating infectious patients with airborne-transmissible diseases, without compromising oxygen therapy for the patient.

How this might change clinical practice
If faced with an influenza pandemic, another severe acute respiratory syndrome–like outbreak, or patients with a dangerous communicable illness, clinicians may be afforded another level of protection through use of a similar device without compromising patient care.

Reducing the shedding of infectious particles from contagious patients may provide additional protection for ambulance or ED personnel. Although it is commonly recommended that surgical masks be used on potentially infectious patients during periods of patient triage or transportation, it is readily acknowledged that such masks do not provide full protection from infection transmission.3 Standard N95 masks may be more effective in containing potentially infectious particles but will not be suitable for most influenza patients ill enough to seek medical care, because these patients will require oxygen (O2) therapy. O2 therapy is commonly administered with the nonrebreathing O2 mask, which is not designed to contain any respiratory droplets. In fact, these masks may actually increase the dispersal of respiratory droplets by jetting them through the mask’s open side vents.8,9 Somogyi et al8,9 reported that the use of the Hi-Ox80 mask, which is designed specifically to deliver high fractional inspired O2 concentrations (FiO2), can provide respiratory isolation if a bacterial-viral filter is placed on its outlet port. However, the mask is expensive, unfamiliar to many, and not likely to be widely available in numbers sufficient for use as a first-line O2 mask in the case of a pandemic.

The implementation and routine use of an entry-level isolation O2 mask during initial patient contact could provide an extra measure of protection to front-line health care workers from potentially contagious patients. Our approach in designing such a mask was to add a nonrebreathing O2 manifold to the familiar N95 mask, which provides excellent viral and bacterial filtration and is already widely distributed. We tested the effectiveness of this “N95 O2 mask” in providing supplemental O2 and compared it to the nonrebreathing mask and to the Hi-Ox80 mask. We then tested the effectiveness of the N95 O2 mask in protecting the wearer from microparticles in the environment and compared it to the criterion standard in this regard, the N95 mask. We also tested how well the N95 and the N95 O2 masks retained microparticles originating from inside the mask. Finally, although the nonrebreathing mask is not designed to provide respiratory protection or isolation, we included it in particle testing because it is common, at least in our institutions, to find health care workers who believe it confers some level of protection to the wearer or the health care provider.

MATERIALS AND METHODS

Study Design
This study is a prospective repeated-measures design. We divided the study into 3 phases. In phase 1, we tested the O2 delivery characteristics of the N95 O2 mask, the Hi-Ox80 mask, and the nonrebreathing mask at resting ventilation and hyperventilation, each at 3 O2 flow rates (to view photographs of the masks, see Figure E1, available online at http://www.annemergmed.com). In phase 2, we tested the protection function (ie, the ability of the mask to filter microparticles from ambient air) of the N95 mask, the N95 O2 mask, and the nonrebreathing mask. In phase 3, we tested the masks’ isolation function (ie, the effectiveness of each mask in containing microparticles generated inside the mask). We did not include the Hi-Ox80 in particle testing, because its protective and isolation function would be that of the particular filter placed on its expiratory port, and this information is already well documented (eg, see Dellamonica et al10). Neither subjects nor investigators were blinded to the type of mask being used for any of the test phases.

Setting
All tests were conducted in a well-ventilated patient room at a university teaching hospital, with the door closed.

Selection of Participants
After receiving institutional ethics research board approval, we obtained signed informed consent from 10 volunteers for each of the 3 phases of the study. Subjects were recruited by posted advertisement. Inclusion criteria were healthy nonsmoking men (without facial hair) or women between the ages of 18 and 60 years, with no active respiratory disease.

Interventions
We tested the O2 delivery characteristics of 3 masks as characterized by the FiO2 that they supplied. The 3 O2 masks we tested were the N95 O2 mask (a modified 3M model 1870; 3M, St. Paul, MN), the modified Hi-Ox80 mask (VIASYS...
HealthCare, Yorba Linda, CA) and the nonrebreathing mask (Airlife Adult Oxygen Mask; Cardinal Health, McGaw Park, IL).

We modified the N95 mask to allow for O₂ administration by adding an O₂ delivery manifold similar to that of a standard nonrebreathing mask. The manifold consisted of a 1-way valve, an O₂ inlet port, and an O₂ reservoir (Figure 1). The Hi-Ox⁸⁰ mask was modified by placing a bacterial-viral filter (DAR Sterivent Mini; Mallinckrodt DAR, Mirandola, Italy) on its expiratory port.⁸

Subjects were fitted with the Hi-Ox⁸⁰ and initially asked to breathe normally (resting condition). An O₂ flow of 2, 4, or 8 L/minute was selected randomly by draw. We chose these O₂ flow rates for 2 reasons. First, the Hi-Ox⁸⁰ is rated to provide clinically useful FIO₂ at these flows.¹¹ Second, using lower flows with O₂ masks may be necessary in case O₂ supplies become limited, as when treating mass casualties (eg, during a pandemic). Subjects were not told of the O₂ flow being administered. Once end-tidal PCO₂ (PETCO₂) and end-tidal PO₂ (PETO₂) reached a steady state (defined as less than a 2 mm Hg change in PETCO₂ during 2 minutes), minute ventilation, PETCO₂, and PETO₂ were recorded for 2 minutes. Subjects were then asked to increase their minute ventilation sufficiently to reduce their PETCO₂ by 10 mm Hg below their resting values (hyperventilation) and maintain that level of PETCO₂. Once steady state was achieved at the target PETCO₂, minute ventilation, PETCO₂, and PETO₂ were again recorded for 2 minutes. Subjects then reestablished steady-state resting ventilation, after which the test was repeated for the other 2 O₂ flow rates. After testing the Hi-Ox⁸⁰ at all 3 flow rates, the other 2 masks were tested (in random order) using the same protocol. The Hi-Ox⁸⁰ mask was tested first because it is the only mask that permits measurement of minute ventilation. We were then able to use the PETCO₂ to match the minute ventilation when testing the other masks.

We tested the protective function of the masks by measuring the extent to which particles originating from ambient air leaked into the mask during normal breathing. We tested the N95 mask (3M model 1870, 3M, for 9 subjects; Aero mask, Aero Co, Southbridge, MA, for 1 subject), the N95 O₂ mask (constructed from the same models of N95 mask stated previously), and the nonrebreathing mask. Six of the subjects were hospital employees who had been previously fit-tested with N95 masks. We therefore used the same model of N95 mask for their tests. The remaining 4 subjects who were not previously fit-tested were arbitrarily supplied with the 3M model 1870. Although there is a possibility this may have introduced variability in our data, the arbitrary use of masks simulates cases in which this mask would be applied to a patient as an infectious barrier. Each mask was prepared in advance by inserting a gas sampling port into the mask material (Figure 2). The particle generator was turned on and infused microparticles freely into the closed room for 20 minutes before subject testing to increase the atmospheric particle concentration in the room to more than 200/cm³. The test mask was placed on the subject’s face, and subjects were instructed to breathe normally. After at least 2 minutes, we recorded particle concentrations outside the mask and then from inside the mask for 30 seconds each.

We tested the isolation function of the same 3 masks by measuring the extent to which particles originating from inside the mask leaked out into the surrounding air. Masks were prepared in advance by inserting sampling and particle infusion ports into the mask. Subjects were instructed to breathe.
Methods of Measurement

O2 flow to the masks was controlled by a calibrated flow meter (Voltek Enterprises, Toronto, Ontario, Canada). Gas was sampled continuously from the oropharynx and analyzed for CO2 (IR1507; Servomex Fairfax, CA) and O2 (UFO130-2; Teledyne-Al, City of Industry, CA) partial pressures (PCO2 and PO2, respectively). Tidal gas was sampled from the oropharynx by a catheter inserted through a sealed port in the mask, which allowed accurate sampling of end-tidal gases without dilution from the high flows of O2.

A particle generator, model 8026 (TSI Inc, Shoreview, MN), was used to generate a steady flow of ultrafine (approximately 0.2 μm) sodium chloride particles that are easily suspended in air. Particle concentrations were measured with Portacount Plus, model 8020 (version 2003 Rev K; TSI Inc), which is rated for detecting the concentration of particles as small as 0.02 μm.12

Data Collection and Processing

PCO2 and PO2 signals were digitized and recorded continuously by a data acquisition and analysis program (Labview; National Instruments, Austin, TX). PETCO2 and PETO2 were identified using a custom peak detection algorithm and converted to fractional concentrations (FETCO2 and FETO2). For each O2 mask, ventilation, and flow combination, average FETCO2 and minute ventilation (where applicable) were calculated during 2-minute steady states for each subject.

FiO2 was calculated for each breath from FETCO2 and FETO2 using the alveolar gas equation13 (FiO2 is a flow-averaged value of the O2 concentration during inspiration and is reflected in the exhaled concentrations of CO2 and O2). For each O2 mask, ventilation, and flow combination, average FiO2s were calculated during 2-minute steady states for each subject.

During particle testing, on average, 15 to 20 discrete measurements were recorded for each 30-second sampling period and entered manually into a spreadsheet for analysis. For each subject, background concentrations recorded outside the mask were averaged.

Outcome Measures

We used FiO2 as the marker of effectiveness of O2 delivery. We assumed the N95 mask to be the criterion standard for particle filtration; clinical equivalence was assumed for masks whose performances were comparable to that of the N95. The protective function of each mask was quantified by measuring the concentrations of particles inside the mask and expressing each discrete measurement as a percentage of average external concentrations. The isolation function of each mask was quantified by measuring the external particle concentrations while infusing particles into the mask and expressing each discrete measurement as a percentage of change from the average background concentrations measured before the particle generator was started.

Primary Data Analysis

Descriptive statistics and graphical methods were used to display our results. We used bar graphs to display average FiO2 values for all subjects. Box plots were used to display data points obtained during particle testing to illustrate the variability in particle concentrations that we observed over time.

RESULTS

All quantitative results are expressed as median (range). With the Hi-Ox80 mask, subjects' minute ventilation and PETCO2 (pooled for all O2 flow rates) were 5.8 L/minute (2.3 to 9.5 L/minute) and 39.9 mm Hg (34.9 to 44.5 mm Hg), respectively, at rest and 14.9 L/minute (9.0 to 23.1 L/minute) and 29.2 mm Hg (24.7 to 33.9 mm Hg), respectively, during hyperventilation. The PETCO2 (our marker for ventilation) for the N95 O2 mask and the nonrebreathing mask (also pooled for all O2 flow rates) was equivalent to that obtained by testing the Hi-Ox80 (39.6 mm Hg [32.8 to 45.7 mm Hg] and 38.2 mm Hg [33.1 to 44.1 mm Hg], respectively, at rest and 29.3 mm Hg [25.3 to 34.0 mm Hg] and 28.9 mm Hg [23.7 to 33.2 mm Hg], respectively, during hyperventilation).

The Hi-Ox80 consistently delivered a higher FiO2 than the other masks, with greater margins at higher O2 flow rates (Figure 3). The FiO2 obtained from the N95 O2 mask was clinically equivalent to that from the nonrebreathing mask for both resting ventilation and hyperventilation. During resting ventilation and at 8 L/minute O2 flow, the FiO2 delivered by the Hi-Ox80 was 0.90 (0.79 to 0.96), consistent with that predicted by the package insert. Under these conditions, the FiO2 with the N95 O2 mask and nonrebreathing mask was 0.68 (0.60 to 0.85) and 0.59 (0.52 to 0.68), respectively.

For protective function, the N95 O2 mask provided the same efficiency of filtration of outside particles as the N95 mask at O2 flow rates of 2 and 10 L/minute (Figure 4). Median particle concentrations inside the N95 and N95 O2 masks at 2 and 10 L/minute were less than 1% of those outside the mask (0.0% to 3.0%). In contrast, high particle concentrations were found inside the nonrebreathing mask, with O2 flow at 2 L/minute (53% [37% to 87%]) and with O2 flow at 10 L/minute (17% [3% to 37%]).
For isolation function, the N95 O₂ mask provided the same efficiency of filtration of inside particles as the N95 mask. There was no increase in external particle concentrations above background values measured outside either mask, regardless of distance from the mask or O₂ flow into the N95 O₂ mask (Figure 5A, B). In contrast, particle concentrations measured outside the nonrebreathing mask were markedly higher than background values at 6 cm and 50 cm from the mask: 800% (62% to 3100%) and 450% (100% to 12,000%), respectively, when O₂ flow rates were 2 L/minute and 330% (15% to 1300%) and 95% (33% to 3000%) when flows were 10 L/minute.

LIMITATIONS

We studied the O₂ delivery characteristics of the 3 masks in healthy volunteers, not patients. The justification for this method is that the marker of effectiveness of O₂ delivery we studied—FiO₂—depends only on the characteristics of the mask, the O₂ flow, and the minute ventilation of the subject. The latter 2 were controlled in this study. Moreover, arterial partial pressure of O₂ and oxyhemoglobin saturation depend not just on the FiO₂ but also on such individual patient factors as the ventilation-to-perfusion ratio and shunt. Therefore, arterial blood gases and oxyhemoglobin saturation measurements in patients with pulmonary and other pathology are not required for evaluation of mask-specific O₂ administration efficiency.

We tested a group of 10 subjects for each phase of the protocol, but several subjects did not participate in all 3 phases of the study. However, for the phase of the study in which an individual subject did participate, he or she tested all 3 masks. Furthermore, the measured parameters of each phase of the study are totally independent of each other.

We studied the ability of the masks to filter microparticles, and we attempt to make inferences on their performance with other sized particles, such as respiratory droplets. Nevertheless, the 0.2-μm microparticles generated by the TSI particle generator are widely used to test for effectiveness of mask fit and filtration and are reasonable surrogates for such infectious particles as viruses (which are 20 to 300 nm), bacteria (tubercle bacillus; 0.2 to 0.6 by 1.0 to 10 μm), and aerosolized respiratory droplets (>10 μm). In vitro testing has shown that N95 material prevents the penetration of approximately 95% of MS2 viruses (approximately 27.5 nm in diameter).

The isolation function of the Hi-Ox⁸⁰ mask with filter was not compared directly with that of the N-95 O₂ mask for 2 reasons. First, its isolation function would reflect the type of filter used, of which a large variety is available. Second, if the FiO₂ of the Hi-Ox⁸⁰ is clinically necessary, the N95 O₂ mask is not a suitable alternative. We propose that the N95 O₂ mask provides an FiO₂ similar to, and therefore is a suitable alternative for, that of the nonrebreathing mask. Still, under some circumstances when isolation function is the critical issue, a direct comparison may be necessary.

Because of the nature of our study setup, it was not possible to blind subjects or investigators to the type of mask being used.

DISCUSSION

There are 2 main findings of our study. The first is that an N95 O₂ mask can deliver O₂ at least as effectively as a nonrebreathing mask. The second is that an N95 O₂ mask retains its filtration function for small particles in both directions. Although it is accepted that a properly fitted N95 mask provides the wearer with a high level of protection from inhaling external particles, our study is the first to demonstrate that the N95 filter material is also effective in preventing...
particles originating inside the mask from escaping into the surroundings in vivo. This could not be assumed from its proven protective function, because the inside of the mask is exposed to moisture, higher gas flows and pressures, and much higher concentrations of particles than those present on the outside.

An implication of these findings is that the N95 O₂ mask may be effective in respiratory “isolation” by restricting the spread of similarly sized infectious particles from an infected patient. In contrast, whereas people are frequently admonished to cover their mouths with their hands when they cough or sneeze to protect others (a practice popularized during the 1918 influenza pandemic), we found that covering the mouth with the nonrebreathing mask provides no reduction in particle concentrations at 6 or 50 cm from the subject breathing at rest. Furthermore, persistence of high particle concentrations inside the nonrebreathing mask casts doubt on any assumption that O₂ flow into a nonrebreathing mask will in any way protect a patient from inhaling others’ respiratory droplets.

Because no controlled studies outlining the full mechanisms of person-to-person transmission of influenza have been published, we must make certain inferences from animal studies and observational and inoculation studies in humans. It appears that influenza is transmitted by droplets (>10 μm), aerosolized droplet nuclei (<10 μm), and by direct and indirect contact (see Bridges et al and Salgado et al for reviews). During the severe acute respiratory syndrome (SARS) outbreaks, it was assumed that reducing the dispersal of respiratory droplets from infected patients would help control the spread of infection. To this end, the World Health Organization guidelines state: “suspected cases should wear surgical masks until SARS is excluded.” Health Canada guidelines similarly recommend that a surgical mask be placed on the patient “until SARS is excluded or the patient is admitted into the room.” However, it is also recognized that a surgical mask “does not provide adequate respiratory protection to the wearer [ie, health care worker] if the infection is airborne.” Recent studies in vitro have demonstrated that surgical masks can allow the penetration of more than 80% of virions 27.5 nm in diameter—besides those that escape from the gaps in the mask seal to the face. The same would obviously apply to the isolation function of a surgical mask when worn by a contagious patient. Although quarantine of the patient may be effective in limiting contacts, it does not reduce the infectious load on those who enter the room and approach the patient or who participate in direct patient care.

When O₂ is administered to a patient, respiratory isolation is even more problematic. Our study confirms earlier work demonstrating that standard O₂ masks do not provide effective containment of droplet or nuclei-sized particles and, furthermore, may even contribute to the pattern and extent of spread. These considerations would be of greatest concern to such front-line health care workers as emergency medical services (EMS) and ED personnel who are required to attend symptomatic patients before any definitive diagnosis is made. The intensity of exposure is increased for these personnel for 2 reasons. First, they may have to provide high-risk interventions such as O₂ administration and endotracheal intubation. Second, the duration of exposure will likely be prolonged because filling of inpatient and critical care areas will result in

Figure 4. Protective function. Internal particle concentrations expressed as a percentage of external concentrations. Median values for the N95 mask and the N95 O₂ mask at 2 and 10 L/min of O₂ flow were all <1%. Median values for the nonrebreathing mask at 2 and 10 L/min of O₂ flow were 53% and 17%, respectively. The boxes outline the 25th and 75th percentiles, the bars indicate the 10th and 90th percentiles, and the dots indicate the outlying values. For quantitative data regarding the protection function of each mask, see Table E1 (available online at http://www.annemergmed.com).
“boarding” of patients in the ED and ambulances. The risk to EMS workers appears to be particularly great when EMS are placed on hospital bypass because it leaves these workers in close quarters with sick patients for prolonged periods.

A number of limitations to the use of the N95 O2 mask may arise in actual clinical practice. One would still have to rely exclusively on health care worker–worn barrier devices when patient isolation is impossible (as during endotracheal intubation or bronchoscopy), as well as for patients for whom a good mask seal is difficult to obtain (for example, edentulous patients or patients with full beards). The N95 O2 mask will also not be suitable for patients requiring an FiO2 greater than 0.7, nebulized medication, invasive or noninvasive ventilatory assistance, or airway protection.

One would also expect that the limitations of the original N95 mask (eg, deterioration of filtration function with prolonged use, excessive handling, and accumulation of moisture) may also apply to the N95 O2 mask. Indeed,

Figure 5. A, Isolation function at 6 cm. External particle concentrations measured at 6 cm from the mask, expressed as a percentage of change from background concentrations. Median values for the N95 mask and the N95 O2 mask at 2 and 10 L/min of O2 flow were indistinguishable from one another. Median values for the nonrebreathing mask at 2 and 10 L/min of O2 flow were 800% and 330%, respectively. The boxes outline the 25th and 75th percentiles, the bars indicate the 10th and 90th percentiles, and the dots indicate the outlying values. B, Isolation function at 50 cm. External particle concentrations measured at 50 cm from the mask, expressed as a percentage of change from background concentrations. Median values for the N95 mask and the N95 O2 mask at 2 and 10 L/min of O2 flow were indistinguishable from one another. Median values for the nonrebreathing mask at 2 and 10 L/min of O2 flow were 450% and 95%, respectively. The boxes outline the 25th and 75th percentiles, the bars indicate the 10th and 90th percentiles, and the dots indicate the outlying values. For quantitative data regarding the isolation function of each mask, see Tables E2 and E3 (available online at http://www.annemergmed.com). NRM, Nonbreathing mask.
increased airflow resistance and the perception of increased work of breathing were commonly experienced by health care workers after prolonged N95 mask use during the SARS outbreak in Toronto. The increased resistance to breathing is likely due to moisture obstructing the pores in the mask material. Increased breathing resistance would reduce the ability of breathless patients to tolerate long-term use of the N95 mask. Although no detailed studies evaluating the duration of effectiveness of the N95 mask have been done, these considerations indicate that the N95 O2 mask may be best suited for short-term use, such as during ambulance transport, hospital triage, and transport from one hospital ward to another (eg from the patient room to the diagnostic imaging department). On the other hand, the inspiratory flow resistance may actually be less than that of the original N95 because the N95 O2 mask includes an O2 reservoir that provides the major part of the inspiratory volume, leaving only small volumes at low flows at end inspiration to be inhaled through the mask filter material.

We tested the masks for only a short period because they were intended to provide a short-term solution to O2 delivery and respiratory isolation at initial patient contact. Extrapolation of these results to more prolonged use should be made with caution.

In conclusion, our study indicates that the N95 O2 mask we constructed can deliver an FiO2 clinically equivalent to that provided by a nonrebreathing mask, although neither is as efficient as the Hi-Ox. Furthermore, the modification of the N95 mask for O2 delivery retains the same filtration function as the N95 mask. This is the first study to confirm that the N95 mask, as well as our modified version of the mask, is effective in retaining microparticles originating inside the mask in vivo. Assuming that the kinetics of microparticle distribution studied in humans is a suitable model to study the risk of transfer of infection in humans, we conclude that for O2-requiring patients, the N95 O2 mask appears to provide protection and respiratory isolation at initial patient contact. Extrapolation of these results to more prolonged use should be made with caution.

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We tested the masks for only a short period because they were intended to provide a short-term solution to O2 delivery and respiratory isolation at initial patient contact. Extrapolation of these results to more prolonged use should be made with caution.
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Figure E1. A, Modified Hi-Ox$^{80}$ mask. B, N95 O$_2$ mask. C, Nonrebreathing mask.
### Table E1. Particle concentrations from the protection phase of the study.*

| Mask                     | Median | Range      | Interquartile Range |
|--------------------------|--------|------------|---------------------|
| N95 mask                 | 0.07   | 0–0.67     | 0–0.15              |
| N95 O₂ mask, 2 L/min     | 0.13   | 0–4.58     | 0–0.36              |
| N95 O₂ mask, 10 L/min    | 0.06   | 0–2.19     | 0–0.33              |
| NRM mask, 2 L/min        | 52.93  | 3.10–141.88| 43.12–75.31         |
| NRM mask, 10 L/min       | 15.26  | 0.27–98.60 | 6.90–29.90          |

NRM, Nonrebreathing mask.

*The protection function of each mask was quantified by measuring the concentrations of particles inside the mask and expressing each discrete measurement as a percentage of average external concentrations.

### Table E2. Particle concentrations measured at 6 cm in front of the mask during the isolation phase of the study.*

| Mask                     | Median | Range      | Interquartile Range |
|--------------------------|--------|------------|---------------------|
| N95 mask                 | −0.13  | −52.73–161.29 | −15.06–20.22       |
| N95 O₂ mask, 2 L/min     | −0.83  | −58.74–131.36 | −11.88–14.05       |
| N95 O₂ mask, 10 L/min    | 3.69   | −93.22–91.19  | −9.91–18.89        |
| NRM mask, 2 L/min        | 472.64 | 11.67–7944.91 | 82.97–1020.59      |
| NRM mask, 10 L/min       | 80.81  | −22.91–3509.63| 24.87–555.24       |

*The isolation function of each mask was quantified by measuring the external particle concentrations while infusing particles into the mask and expressing each discrete measurement as a percentage of change from the average background concentrations.

### Table E3. Particle concentrations measured at 50 cm to the side of the mask during the isolation phase of the study.*

| Mask                     | Median | Range      | Interquartile Range |
|--------------------------|--------|------------|---------------------|
| N95 mask                 | 0.17   | −46.97–179.88 | −11.64–16.52       |
| N95 O₂ mask, 2 L/min     | 5.10   | −44.31–67.51  | −7.84–17.71        |
| N95 O₂ mask, 10 L/min    | 9.81   | −85.92–90.91  | −2.05–26.62        |
| NRM mask, 2 L/min        | 418.73 | 68.33–27442.17 | 317.48–506.74      |
| NRM mask, 10 L/min       | 93.61  | −80.64–6057.74| 56.65–182.77       |

*The isolation function of each mask was quantified by measuring the external particle concentrations while infusing particles into the mask and expressing each discrete measurement as a percentage of change from the average background concentrations.