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A crossover trial investigating the atmospheric content of improvised respirators

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Abstract

Introduction: This study was designed to determine the respiratory safety of improvised respirators based on modified full-face snorkel masks, making comparisons with a purpose-designed mask

Methods: This is a prospective crossover study conducted on ten recruits. Volunteers wore snorkel masks mated to an anaesthetic heat and moisture exchange filter. The system was worn at rest then during exercise. Gases were sampled from the mask at 5-min intervals.

Results: The modified snorkel was satisfactory in seven participants. For three carbon dioxide concentrations were >1%. Two participants exposed to excessive CO_2 also experienced oxygen concentrations <19%. All participants exposed to unsatisfactory gas mixtures were non-white.

Conclusions: Modifying snorkel masks changes the way that gases circulate through the system. These modifications increase the risk of rebreathing in some users, which may yield an unsafe gas mixture. These improvised masks cannot be recommended as a substitute for purpose-designed equipment.

Keywords

Personal protective equipment, COVID-19, safety

Introduction

Shortfalls in personal protective equipment (PPE) during the first wave of COVID-19 led many groups to repurpose snorkel masks as respirators. The most widely available proposal was based on a full-face Decathlon snorkel mask mated to a heat and moisture exchange (HME) filter by a 3 D-printed adaptor.

These are already being used by staff in many healthcare facilities without rigorous quality assessment. This study was designed to test the gases delivered by such an improvised system.

Methods

Comparisons were made between a Sundstrom SR-100 reusable mask (Sundstrom Safety AG, Lagan, Sweden) and an assembly comprising a Decathlon full-face snorkel mask (Decathlon, Villeneuve d'Ascq, France), an adaptor made using a Prusa i3 Mk2 printer (Pruza Research, Praha, Czech Republic), and a ClearTherm 3 HME filter (Intersurgical, Wokingham, UK).

Inspired oxygen (F_iO_2) and carbon dioxide (F_iCO_2) concentration was measured every 5 min using the analyser of a Dräger Primus anaesthetic machine (Dräger UK, Hemel Hempstead, UK). Twenty minutes wearing each mask were spent at rest, then 20 min of light exercise using an aerobic stepper to simulate physical work. A 5-min washout (with the mask doffed) was inserted between phases.

A convenience sample of ten was selected based on recommendations provided in the British Standard for mask certification.[1] Recruitment was purposeful to ensure a mix of gender and ethnicity.

Results

Six males and four females were recruited. Three participants were white, two black, four Asian, and one of 'other' ethnicity. The mean (95% CI) age was

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38.6 (33·8–43·4) and mean (95% CI) BMI was 27·8 (23·5–32·2). There were no significant differences in BMI by gender ($p = 0{\cdot}44$) or ethnicity ($p = 0{\cdot}49$).

Gas composition overall did not significantly differ between test phases (Table 1), however the improvised respirator delivered F_iCO_2 >1% (the limit specified in British Standards[2]) for three individuals. Nine measures from these participants showed CO_2 over 1% (seven measured at rest, two on exertion). For two participants the 2% F_iCO_2 safety limit imposed by the study protocol was breached, requiring testing be abandoned. Hypercapnic mixtures coincided with low F_iO_2 in two participants.

The two participants in whom the test was stopped early for safety reasons were of Asian ethnicity. The third participant exposed to >1% CO_2 (but for whom the test did not breach safety limits) was of 'other' ethnicity. A third participant, of black ethnicity, requested their test be stopped due to discomfort.

The purpose-designed mask delivered acceptable gas compositions and comfort at all test points.

Discussion

The improvised system did not provide a universally safe gas mixture. Some speculation on the point of failure is possible.

The mask is functionally divided into two compartments separated by a membrane (Figure 1). Fresh air reaches the respiratory chamber via a chamber in front of the eyes. One-way valves prevent expired gases returning to the eye chamber. Expiratory flow is directed through unvalved channels running along the outer

Table 1. Gas analysis by test-phase.

	Rest phase		Exercise phase		
Measure	**Mean**	**95%CI**	**Mean**	**95%CI**	***p***
Improvised system					
Inspired O_2 (%)	19.7	19.0–20.3	19.9	19.4–20.3	0.14
Inspired CO_2 (kPa)	0.5	0.1–0.9	0.0	0.0–0.6	0.07
Purpose-designed system					
Inspired O_2 (%)	20.1	20.0–20.2	20.0	19.9–20.1	0.223
Inspired CO_2 (kPa)	0.2	0.1–0.3	0.2	0.1–0.3	0.375

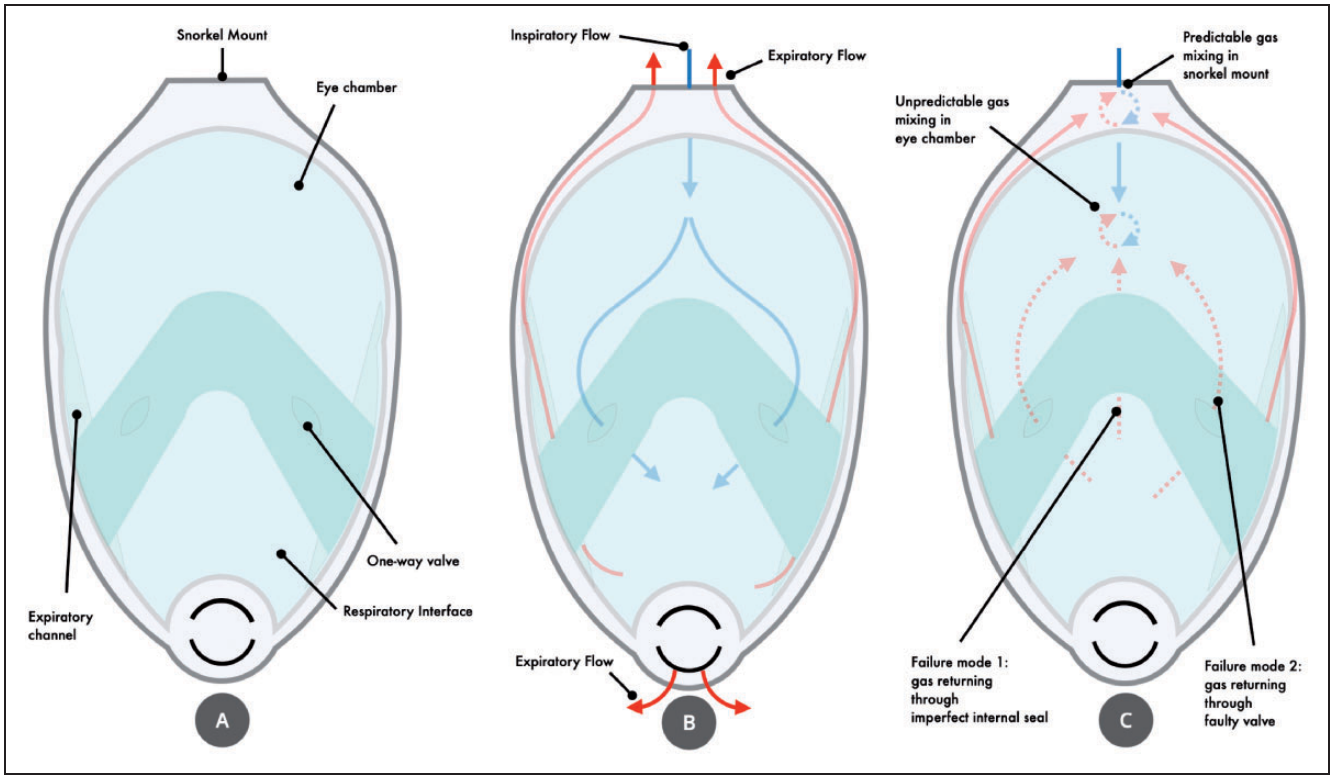

Figure 1. Schematic diagram depicting components of the facemask (a), normal gas paths through the system (b), and potential sources of inspiratory and expiratory gas mixture (c).

edges of the mask back towards the snorkel mount, and through a valved outlet on the front of the mask.

Inspired and expired gases can mix in the adaptor, and no valves separate the adaptor from the eye-chamber. The degree to which the streams mix varies with respiratory effort and rate, but will occur to some degree in all users.

Problems worsen if unidirectional flow between eye-chamber and respiratory interface cannot be maintained, for example by faulty valves or an inadequate seal of the internal membranes. We believe this to be the source of failure in our three participants given the high degree of rebreathing observed. Although it is not known how these snorkel masks were developed, a potential deficiency of even purpose-designed respirators is that the original measurements on which they were based was largely taken from white males.[3] Facial dimensions differ significantly by gender and ethnicity,[4] so it is plausible that the masks' internal membrane does not reliably seal in some users.

Prolonged exposure to high F_iCO_2 is hazardous.[5] Inspired concentrations above 1% yield observable increases in minute volumes, and a subjective sensation of dyspnoea begins at 2%. Impaired CO_2 elimination can result in drowsiness, confusion, and in extreme cases, unconsciousness. Improvised masks could therefore be hazardous when worn over a period of duty.

Finally, this study makes no claims on the improvisation's filtration efficacy (i.e. viral protection). We address this issue fully in a related paper,[6] but in brief our data cast doubt on whether improvised systems provide viral protection for most users.

Our data suggest that improvised respirators cannot be recommended as a substitute for purpose-designed equipment.

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