Manual Conservation of Supplemental Oxygen in Low-Resource Settings During the COVID-19 Pandemic

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Summary Statement: Using a simulated adult COVID-19 patient with hypoxemia, we investigated whether caregivers interrupting oxygen flow by manually occluding oxygen tubing with pliers during exhalation can conserve oxygen while maintaining oxygenation. Oxygen pinching reduced oxygen use by 51% to 64%, maintained simulated oxygen saturation between 88% and 90%, and increased simulated average alveolar partial pressure of oxygen from a room air baseline of approximately 131 to 294–424 mm Hg compared with 607 mm Hg with 10 liters per minute (LPM) continuous oxygen flow. Simulation provided a methodology to rapidly evaluate a technique that has begun to be used with COVID-19 patients in low-resource environments experiencing an acute oxygen shortage. (*Sim Healthcare* 17:136–137, 2022)

Key Words: Oxygen conservation, oxygenation, acute oxygen shortage.

PROBLEM: CONTEXT AND OBJECTIVE

In response to acute oxygen shortages in India, we conceived and investigated a simple and readily implemented method for caregivers to extend the duration of oxygen cylinders used to treat hypoxemia induced by COVID-19 while patients await hospital admission. Caregivers manually occlude the oxygen tubing supplying supplemental oxygen with pliers during exhalation ("oxygen pinching") to reduce oxygen waste and prolong the duration of cylinders. A similar manual approach using a valve was described by Cotes in 1956 and is now automated in oxygen conservers. Tobin et al (2020)[1] described patients with COVID-19 receiving supplemental O_2 (6–15 liters per minute [LPM]) with oxygen saturations (Sp_{O_2}) from 62% to 76% and arterial oxygen partial pressures (Pa_{O_2}) from 36 to 45 mm Hg. This study is aimed at manually reducing oxygen flow during exhalation, not optimizing continuous supplemental oxygen flow rates, to conserve oxygen. Using a patient simulator, we investigated whether this oxygen-pinching technique could conserve oxygen while maintaining oxygenation.

METHODS AND MATERIALS

We programmed a Human Patient Simulator (HPS vB; CAE Healthcare, Sarasota, FL) that physically consumes oxygen to simulate an adult COVID-19 patient with hypoxemia (see Figure 1, Supplemental Digital Content 1, which demonstrates the simulation setup, http://links.lww.com/SIH/A736). Simulator settings were spontaneous ventilation at 30 beats per minute (BPM), inspiratory:expiratory ratio 1:2, tidal volume 500 mL, and shunt fraction 0.48 (to obtain a simulated room air Pa_{O_2} of 55 mm Hg). Pa_{O_2}, Sp_{O_2}, and alveolar oxygen partial pressure (PA_{O_2}) values estimated by the HPS models were recorded while breathing (*a*) room air, (*b*) 10 LPM continuous supplemental oxygen, and (*c*) 10 LPM supplemental O_2 manually interrupted during exhalation. An E-cylinder provided the HPS with supplemental oxygen via a nonrelieving pressure regulator (M1-870-15FG; Western Enterprises, Westlake, OH) and a nonrebreather facemask (#1059; Teleflex, Wayne, PA). A zip tie secured the facemask tubing inlet to the regulator outlet to prevent the tubing from popping off when crimped at flows exceeding 10 LPM. Three participants simulated the role of caregivers pinching the facemask's oxygen tubing during exhalation immediately downstream of the pressure regulator with a set of pliers (4 3/4 in, flat nose, smooth crimping surfaces; Harbor Freight Tools, Calabasas,

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S.L. is an inventor of the Human Patient Simulator (HPS). He and the University of Florida used to receive royalties on the now expired patent rights to the HPS.

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CA; see Figure 1, Supplemental Digital Content 1, which shows the experimental setup, http://links.lww.com/SIH/A736). Crimping with fingers only does not stop oxygen flow through the internal ridges in kink-resistant oxygen tubing. Because mask fogging during exhalation by patients does not occur with the HPS, participants instead used movement of the bellows, representing the lungs, to time pinching to exhalation. Each run lasted 14 minutes based on the time for PAO_2, PaO_2, and SpO_2 to stabilize in the HPS. To calculate oxygen use, the weight of the E-cylinder after a run was subtracted from the weight before the same run. Weight was measured with a digital scale (Model EK-12Ki, 12,000 × 1 g; A&D Engineering, San Jose, CA). The same oxygen tubing was crimped for all experiments. A leak test was performed after all experiments by immersing the crimping site underwater with oxygen flowing.

RESULTS

Oxygen pinching reduced oxygen use between 51% and 64%, varying between participants. Baseline PAO_2, PaO_2, and SpO_2 levels on room air were 131 mm Hg, 53 mm Hg, and 85%, respectively, and 607 mm Hg, 72 mm Hg, and 93% on 10 LPM of continuous supplemental oxygen. Average PAO_2, PaO_2, and SpO_2 levels from the 3 oxygen-pinching runs were 348 mm Hg, 62 mm Hg, and 89%. Although PAO_2, PaO_2, and SpO_2 were reduced with oxygen pinching compared with 10 LPM continuous supplemental oxygen, all 3 indices improved compared with breathing room air (see Figures 2–4 and Table, Supplemental Digital Content 2, for PAO_2, PaO_2, SpO_2, and O_2 use on different runs, http://links.lww.com/SIH/A737). No leak occurred at the crimping site.

DISCUSSION

The simulator was primarily used to refine the oxygen-pinching technique (eg, requiring pliers instead of fingers), determine its feasibility, and estimate oxygen use reduction. Oxygen pinching should prolong the duration of any oxygen cylinder, including J-size (6800 L), used on patients with COVID-19 in India.

The simulator was not used to predict whether oxygenation could be maintained during oxygen pinching in actual patients with COVID-19. That would have required a validated predictive model of COVID-19 pathophysiology that the simulator does not have. Instead, the hypoxemia and tachypnea of a patient with COVID-19 were simulated; therefore, although the simulated PaO_2, SpO_2, and PAO_2 data were helpful for comparison between runs, they were not predictive of what would happen in actual patients with COVID-19.

The results of the simulator study were shared with a physician in India who had initially approached us for help. He independently made the decision to inform caregivers for his patients with COVID-19 about the oxygen-pinching technique and reported that it was being used successfully.

The theoretical maximum 67% reduction of oxygen use at an inspiratory:expiratory ratio of 1:2 was not achieved because manually timing pinching with exhalation is difficult. Our simulated data, however, suggest that oxygen pinching may more than double the life of oxygen cylinders while maintaining oxygenation.

Limitations

The data from three participants established that there is participant-dependent variability. Although oxygen pinching improved simulated SpO_2 and reduced oxygen use for all participants, these improvements may be unattainable in patients with COVID-19 due to caregiver fatigue, lack of caregiver replacements, and severity of COVID-19 symptoms. In patients with COVID-19, respiratory rhythm would be less regular than the simulator, making it more challenging to time the pinching. The oxygen tubing may eventually fatigue and leak at the crimping site; we recommend initially crimping 6 to 12 in from the inlet, moving closer to the inlet by 0.5-in increments at regular intervals and having a spare facemask ready.

CONCLUSIONS

During dire conditions in India, simulation provided a quick method to develop, refine, and collect data on an immediately actionable technique for prolonging the duration of an oxygen cylinder. Data were rapidly shared with colleagues in India so that they could evaluate the data and decide whether to use the technique to address the acute oxygen shortage. This work is intended to help address health disparities that have been exacerbated during COVID-19.

REFERENCE

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