The use of oxygen hoods in patients failing on conventional high-flow oxygen delivery systems, the effects on oxygenation, mechanical ventilation and mortality rates in hypoxic patients with COVID-19. A Prospective Controlled Cohort Study

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ABSTRACT

Introduction: Efforts to meet increased oxygen demands in COVID-19 patients are a priority in averting mechanical ventilation (MV), associated with high mortality approaching 76.4–97.2%. Novel methods of oxygen delivery could mitigate that risk. Oxygen hoods/helmets may improve: O_2-saturation (SaO2), reduce in-hospital mechanical ventilation and mortality rates, and reduce length of hospitalization in hypoxic Covid-19 patients failing on conventional high-flow oxygen delivery systems.

Methods: **Design** Prospective Controlled Cohort Study.

Setting Single Center.

Participants All patients admitted with a diagnosis of COVID-19 were reviewed and 136/347 patients met inclusion criteria.

Study period 3/6/2020 to 5/1/2020.

136 participants completed the study with known status for all outcome measures.

Intervention or exposure Oxygen hoods/helmets as compared to conventional high-flow oxygen delivery systems.

Main outcome(s) and measure(s): 1) Pre and post change in oxygen saturation (SaO_2).

2) In-hospital Mechanical Ventilation (MV).

3) In-hospital Mortality.

4) Length of hospitalization.

Results: 136 patients including 58-intervention and 78-control patients were studied. Age, gender, and other demographics/prognostic indicators were comparable between cohorts.

Oxygen hoods averted imminent or immediate intubation/MV in all 58 COVID-19 patients failing on conventional high-flow oxygen delivery systems with a mean improvement in SaO_2 of 8.8%, p < 0.001.

MV rates were observed to be higher in the control 37/78 (47.4%) as compared to the intervention cohort 23/58 (39.7%), a difference of 7.7%, a 27% risk reduction, not statistically significant, OR 95%CI 0.73 (0.37–1.5).

Mortality rates were observed higher in the control 54/78 (69.2%) as compared to the intervention cohort 36/58 (62.1%), a difference of 7.1%, a 27% risk reduction, not statistically significant OR 95%CI 0.73 (0.36–1.5).

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Conclusion: Oxygen hoods demonstrate improvement in SaO_2 for patients failing on conventional high-flow oxygen-delivery systems and prevented imminent mechanical ventilation.

In-hospital mechanical ventilation and mortality rates were reduced with the use of oxygen hoods but not found to be statistically significant.

The oxygen hood is a safe, effective oxygen-delivery system which may reduce intubation/MV and mortality rates. Their use should be considered in treating hypoxic COVID-19 patients. Further research is warranted.

Trial registration: ClinicalTrials.gov Identifier: NCT 04407260.

What this research paper adds?

What is already known?

- A previous randomized controlled study found that oxygen hoods resulted in improved oxygenation, decreased mechanical ventilation and mortality rates in patients with Adult Respiratory Distress Syndrome (ARDS).
- COVID-19 associated respiratory failure demonstrates similarities to ARDS related respiratory failure but is not identical in its pathophysiology.
- Preliminary experience in Italy suggested oxygen hoods improved oxygenation in COVID-19 patients failing on other forms of conventional oxygen delivery systems.
- There were no clinical trials investigating whether oxygen hoods would benefit and improve oxygenation, decrease the need for mechanical ventilation, or mortality rates in COVID-19 patients.

What this study adds?

- Our study was conducted during the surge in COVID-19 admissions to our hospital institution. It supports the role of oxygen hoods to improve patient oxygenation and prevent immediate and imminent intubation in patients failing on conventional high-flow oxygen delivery systems during the COVID-19 pandemic.
- Our study observed reductions in mechanical ventilation and mortality rates using the oxygen hoods in patients with COVID-19 impending respiratory failure. However these observations in mechanical ventilation and mortality did not reach the threshold for statistical significance.

1. Introduction

The shortage of ventilators worldwide during the COVID-19 crisis is an ongoing front-line challenge facing Healthcare practitioners [1]. Large numbers of patients require ventilator management with a limited supply to meet these high demands during the Coronavirus pandemic [2]. Meeting the increased oxygen demands of patient's is a critical priority in delaying or avoiding intubation and mechanical ventilation (MV), associated with a high mortality approaching 76.4–97.2% [3,4]. Novel methods of oxygen delivery to patients may help mitigate this risk while more resources become available [5–8]. This could provide needed time for emergency supportive measures to catch up with the critical oxygenation demands of patients worldwide [5].

Oxygen hoods routinely used in undersea & hyperbaric medicine centers were implemented once available at our institution in patients whose oxygen saturation (SaO_2) was below 90% and were failing on conventional high-flow oxygen delivery systems. These conventional oxygen delivery systems routinely used include non-rebreather masks (NRB), venturi masks (VM), high-flow nasal cannula (HFNC), continuous positive airway pressure (CPAP), or bilevel positive airway pressure (BiPAP) [7–9].

The total cost of the hood apparatus varies, but is approximately $250.00 (US) [10]. The oxygen hood system is cost-effective and could help address the demand for effective supplementary alternative oxygen delivery systems in the US and developing nations when compared to ventilator costs which are expensive and where supply is critical [11]. The oxygen hoods can be cleaned and reused according to the position paper published by the European Committee on Hyperbaric Medicine (ECHM) during the Covid-19 pandemic [12]. See Fig. 1 below.

1.1. Objectives

1) To compare the differences in oxygenation before and after the use of oxygen hoods on COVID-19 patients failing on conventional high flow oxygen systems.
2) To compare mechanical ventilation rates, mortality rates, and length of hospitalization in COVID-19 patients failing on conventional oxygen delivery systems who are subsequently placed on oxygen hoods as compared to COVID-19 patients failing on conventional high flow oxygen delivery systems prior to the availability of oxygen hoods.
3) To determine which risk factors, and whether the use of the intervention oxygen hoods can predict the outcomes mechanical ventilation and mortality rates.

Fig. 1. Oxygen Hood Delivery System with HEPA Filter and Optional Positive End Expiratory Pressure (PEEP) Adaptor. The apparatus is attachable to flowmeters in negative pressure isolation rooms.

2. Methods

2.1. Study design and setting

The first cases of confirmed COVID-19 presented to our institution in Westchester, NY on 3/6/2020. The oxygen hoods were available for patient use on 4/3/2020. The study period includes 3/6/2020 to 5/1/2020. Once the oxygen hoods became available ALL COVID-19 patients failing on conventional high flow oxygen delivery systems (non-rebreather masks, high-flow nasal cannula, CPAP, BiPAP) with an SaO_2 below 90%, declining clinical status, and imminent need for intubation were referred for evaluation and use of the oxygen hood to potentially prevent the need for intubation and MV [13]. These patients represented severe refractory cases of respiratory failure requiring immediate or imminent mechanical ventilation prior to the availability of oxygen hoods.

Patients using or failing on conventional high-flow oxygen delivery presenting prior to oxygen hood availability served as controls. Controls were selected if they required conventional high-flow oxygen delivery systems to maintain SaO_2 above 90%; or if they required mechanical ventilation due to already failing on conventional high-flow oxygen delivery systems. The intent was to balance intervention and control cohorts for respiratory disease severity.

All patients included those testing positive for COVID-19 using PCR swabs and/or diagnosis based on clinical/laboratory standard diagnostic criteria [14]. Medical management included evolving standard treatment regimens such as Hydroxychloroquine/Azithromycin, proning and other regimens widely used at the time of this study [15].

2.2. Patient and public involvement

Patients were not involved in the decision process for this study as our alternative high-flow oxygen delivery method through the oxygen hood was already an accepted intervention for delivering high-flow oxygen in the Undersea and Hyperbaric Medicine department. In prior studies it was also found to be an alternative to intubation in patients suffering from ARDS prior to COVID-19.

2.3. Study protocol

2.3.1. Intervention

The oxygen hoods were attached to the oxygen flowmeters in negative-pressure ventilation rooms via a modified adapter (Sully-adaptor), developed in the department for this purpose. The oxygen hoods required a high-flow rate minimally set at 30 L/min. Flowmeters, in patient rooms, can supply rates exceeding 30 L/min when turned to the full-flush position (40–60 L/min). Full-flush is when the knob on the flowmeter was turned to the fully open position or until it stopped turning [16]. This is done irrespective of the standard ball indicator which usually reads to a maximum of 15 liters/min. The higher flow rates (all sources of oxygen delivery) required the main oxygen supply pressure to be increased accordingly to support the high-flow demands throughout the hospital. HEPA filters (Hudson RCI Bacterial/Viral Filter, or Ultipor 100 Filter) were placed on the oxygen hood exhaust and had a reported Bacterial/Viral Filtration Efficiency (VFE) equivalent to 99.999+% [17]. These filters helped reduce the exposure risk to staff whereas conventional high-flow delivery systems lack this safeguard and flow freely as open systems to the surrounding environments unfiltered.

A Positive-End-Expiratory-Pressure (PEEP) adaptor is an attachment option available for use with the oxygen hoods, but controversy exists on using PEEP in COVID-19 patients [18]. The excess oxygen released from the filtered exhaust manifold of the hood was subsequently vented from the negative-pressure ventilation rooms. This reduced the risks associated with increased oxygen levels in confined spaces including the leaks inherent in all conventional high-flow oxygen delivery systems. The

transparent oxygen hood also allows for visual assessment of the patient's head.

2.3.2. Outcome measures

Oxy-hemoglobin saturation is continuously measured by pulse-oximetry including immediately before and after oxygen hood placement. Serial arterial blood gas (ABG) measurements are not widely used due to the invasiveness of recurrent arterial punctures, bleeding, thrombosis, and over-extended staff burdens during the pandemic. Clinical decisions were frequently made based on pulse-oximetry, clinical, and laboratory assessments of respiratory decompensation and failure.

Patients were followed to discharge/survival, or in-hospital mortality as endpoints in both control and intervention cohorts. Patients who were Do Not Intubate (DNI)/Do Not Resuscitate (DNR) status, and those receiving convalescent plasma antibodies (started on 4/16/2020) were evaluated separately in subgroup analysis. The sub-group of DNI/DNR status patients who expired while in-hospital were reassigned to the intubated group and studied as if full-code status, as they otherwise would have been intubated if not for DNI/DNR status.

Length of stay (LOS) was measured however this metric may be unreliable due to variable stages in disease presentation at time of hospital admission. SaO2, intubation/MV, and mortality during hospitalization were the primary clinical endpoints.

Prognostic/confounding covariates were collected through the Electronic Medical Record (EMR) with redundant chart review by study personnel to ensure accuracy. These Centers for Disease Control (CDC) reported prognostic indicators measured upon presentation/admission included: age, Body Mass Index [BMI], gender, chronic lung disease (COPD, Asthma) [CLD], cardiovascular disease (CAD, CHF, Chronic Dysrhythmia) [CVD], chronic kidney disease [CKD], immunosuppression (history of cancer, immunosuppressive medication, HIV) [Immunosuppression], diabetes mellitus [DM], and pertinent lab markers (see Table 1) [14].

2.3.3. Outcome variables of interest

Routine follow-up evaluation was maintained until final in-hospital outcomes were known for all the following:

1) Oxygen Difference pre/post-hood (SaO_2 difference, %)
2) Intubation/MV status (Y/N)
3) Survival/Mortality (Y/N)
4) Hospital Length of Stay (days)

2.3.4. Inclusion criteria

- Hospital census was reviewed for ALL patients seen in the ED and admitted with COVID -19 diagnosis experiencing hypoxia requiring supplemental high-flow oxygen delivery or mechanical ventilation, along with those failing on these high-flow oxygen systems.
- Consent (native language services provided).
- No limitations/restrictions based on age, gender, race/ethnicity, comorbidities, pregnancy status, DNR/DNI status.

2.3.5. Exclusion criteria

- $SaO_2 > 90\%$ and controlled on room air (RA) or low-flow O_2-delivery system (nasal cannula, simple mask, or venturi-mask).
- Confinement anxiety post-oxygen hood placement with request for removal.

2.3.6. Randomization/blinding

Randomization was not possible as it is unethical to deny a hypoxic patient an alternative approved means of oxygenation for patients failing on conventional oxygen delivery systems. There was no blinding of participants or investigators.

Table 1

Oxygen saturation levels among COVID-19 patients failing on conventional high flow oxygen delivery systems and immediately after receiving hyperbaric oxygen hoods.

	n	Minimum SaO2 (%)	Maximum SaO2 (%)	Mean SaO2(%)	% Change pre and post SaO$_2$	Paired t	Sig (2-tailed)
[a]High Flow Delivery System SaO$_2$	58	72	94	85.7	8.8	17.009	P < 0.001
Post Oxygen Hood SaO$_2$	58	83	100	94.5			

Hypothesis.

Ho: There is no difference in oxygenation pre/post O$_2$-hood in COVID-19 patients who were failing on conventional high-flow oxygen delivery systems.

Ha: There is a difference in oxygenation pre/post O$_2$-hood in COVID-19 patients who were failing on conventional high-flow oxygen delivery systems.

[a] This includes patients failing on Non-Rebreather (NRB) masks, High-flow nasal cannula, CPAP, or BiPAP.

2.3.7. Comparison/control group

The control cohort included hypoxic COVID-19 patients presenting for treatment prior to 4/3/20 when hyperbaric oxygen hoods were not available. The patients maintained on conventional O$_2$-delivery systems or failing on these systems and requiring mechanical ventilation prior to the availability of oxygen hoods were studied.

2.3.8. Sample size estimate

Using an alpha cut off = 0.05, power = 0.90, with minimum effect size differences of 10% and 20% in mechanical ventilation or mortality, would require a minimal sample size of 526 and 158 patients, respectively.

2.3.9. Sensitivity analysis

Sensitivity analysis was not required as there was no missing outcome data from either cohort.

3. Results

3.1. Primary outcomes

Between 3/6/2020 and 5/1/2020 a total of 347 patients were evaluated in the emergency department and admitted to the hospital with a diagnosis of COVID-19 and respiratory symptoms. 63 consultations were conducted, 58 patients met inclusion criteria and were placed on oxygen hoods, see Fig. 2 Flowchart.

211 patients were excluded who were maintained on room air or on low-flow oxygen delivery systems [nasal cannula (NC), (RA), simple mask, or venturi-mask] throughout admission, or those discharged directly from the emergency department and considered stable for outpatient management.

A total of 78/347 patients who did not receive oxygen hoods and were maintained on conventional high-flow oxygen delivery systems during hospitalization or who had failed conventional high-flow oxygen delivery and required mechanical ventilation were used as controls.

The total sample size included known final status outcomes on all 136 patients in both cohorts by 5/29 including: home-discharge status, mechanical ventilation status, in-hospital mortality, and length of stay.
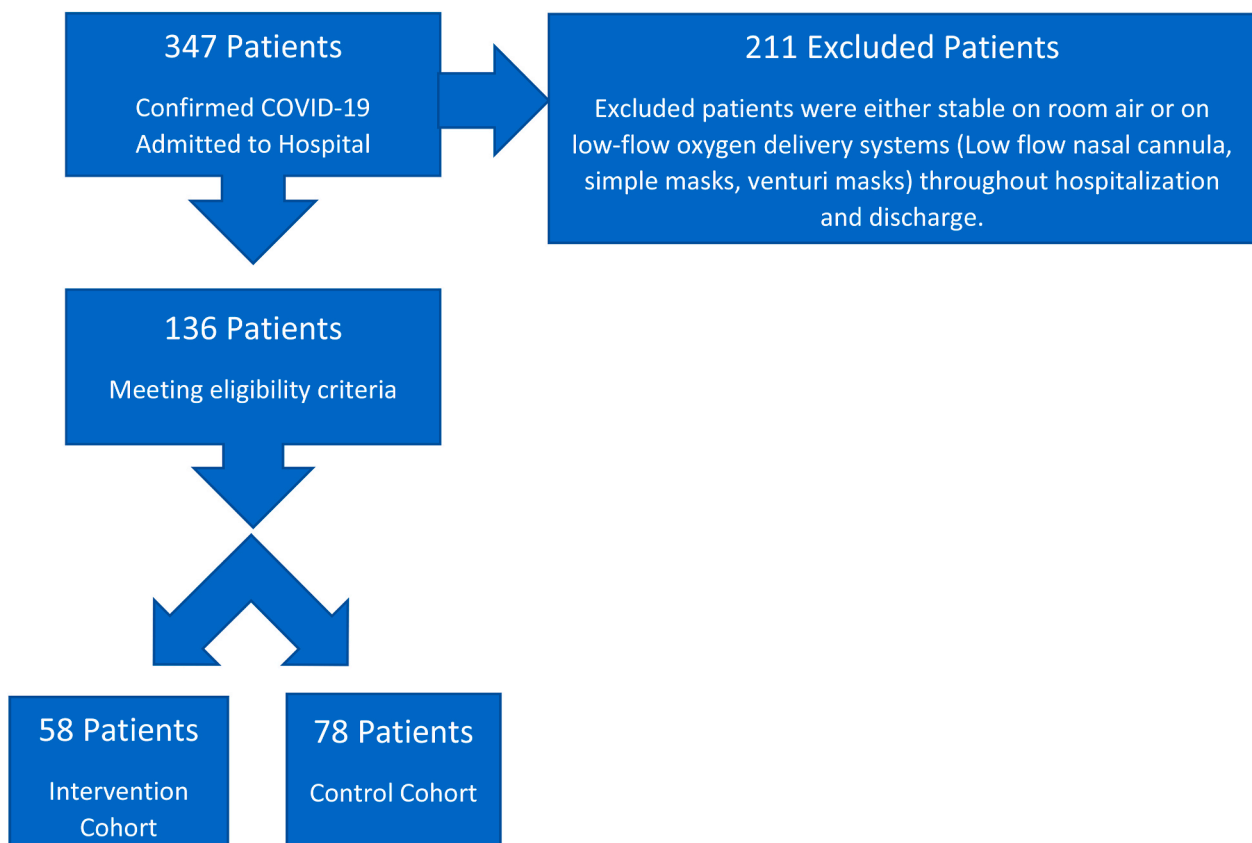

Fig. 2. Flowchart.

There was no missing outcome data to report in either cohort. A total of 136 patients were studied [19].

58/58 patients demonstrated immediate improvement in their oxygen saturation to above 90%. The overall mean improvement in SaO_2 was 8.9%, 95%CI (7.8–9.8). See Table 1.

3.2. Characteristics of participants included in the study

The intervention and control cohorts were compared and not found to have statistically significant differential levels of comorbidities, or potential confounding factors with the exception of Diabetes (DM), Chronic Kidney Disease (CKD), as these were higher in the control as compared to the intervention group. Convalescent plasma antibody administration was higher in the intervention than the control group. The CKD and Plasma covariates had few events in at least one cell with events <5. Differences in CKD history between the cohorts were observed to be significant but differences in creatinine levels upon admission between the cohorts was not found to be statistically significant. The comorbidity chronic lung disease was observed to be higher in the control group 13/78 (17%) as compared to the intervention group 7/58 (12%); whereas smoking was lower in the control 20/66 (26%) as compared to the intervention group 19/55 (35%). Neither chronic lung disease nor smoking reached the threshold for significance (p = 0.45); (p = 0.62) respectively. Cardiovascular disease was higher in the control 28/78 (36%) as compared to the intervention group 14/58 (24%) but was not found to be statistically significant. These findings were similar whether equal variances were assumed or not. There were differences in lab markers of disease between both groups however none of these rose to the threshold of significance, see Table 2.

3.3. Mechanical ventilation and mortality rates in the total sample

The total sample included 60/136 (44.1%) patients that required and 76/136 (55.9%) patients that did not require mechanical ventilation (MV). Mortality in the total sample was observed to be 45/60 (75%) in the patients requiring mechanical ventilation and 42/71 (59.2%) in the patients not requiring mechanical ventilation, or a difference of 15.8% and a 107% increase in mortality in the ventilated patients. These observed differences were not found to be statistically significant OR 95% CI 2.07 (0.98–4.34). See Table 3a.

3.4. Mechanical ventilation and mortality rates in the intervention and control cohorts

Mechanical ventilation rates were observed to be higher in the control 37/78 (47.4%) as compared to the intervention cohort 23/58 (39.7%), a difference of 7.7% or a 27% reduction in the MV rate in the group receiving the oxygen hoods, this reduction was not found to be statistically significant, OR 95%CI 0.73 (0.37–1.5).

Mortality rates were observed to be higher in the control 54/78 (69.2%) as compared to the intervention cohort 36/58 (62.1%), a difference of 7.1% or a 27% reduction in mortality in the group receiving oxygen hoods, this reduction was not found to be statistically significant, OR 95%CI 0.73 (0.36–1.5).

The mean length of hospitalization was observed to be 12.62 days in the intervention and 10.13 days in the control cohort. The intervention cohort receiving oxygen hoods experienced a longer LOS than the control cohort, this reduction was not found to be statistically significant, Mean 95%CI, 2.49 days (−0.37 to 5.35). See Table 3b.

Table 2
COVID-19 demographic characteristics and coexisting conditions among intervention cohort receiving oxygen hoods and control cohort receiving conventional high flow oxygen delivery.

Characteristic or condition N = 136	Intervention cohort[a] (n = 58)	Control cohort (n = 78)	p-value Pearson χ^2	[a]Mean Difference 95%CI Independent t-test
Age -mean (yrs.) Range	68 (25–93)	70.4 (26–98		−2.4 (−3.0 to 8.0)
BMI kg/height (m²) Range	28.2 (17.1–47.4)	29.7 (14.8–75.6)		−1.5 (−7.6 to 2.8)
Male gender no/total, (%)	42/58, (72)	48/78, (61.5)	0.19	
Comorbidities, no./total[b] (%)[c]				
Smoking history	19/55 (35)	20/66 (26)	0.62	
CLD	7/58 (12)	13/78 (17)	0.45	
CVD	14/58 (24)	28/78 (36)	0.14	
CKD	4/58 (6.9)	17/78 (22)	0.02[d]	
Immunosuppression	5/58 (8.6)	11/77 (14)	0.31	
DM	17/58 (29)	40/78 (51)	0.01	
DNR	25/58 (43)	22/78 (28)	0.71	
Plasma	21/58 (36)	2/78 (2.6)	<0.001[d]	
Admission Lab **Mean Range**	Mean 95%CI n	Mean 95%CI n		
D-Dimer (ng/mL)	4049 (187–52915) n = 52/58	5611 (187–55559) n = 49/78		−1563 (−6151 to 3026)
Lymphocyte count (absolute cell count)	999 (92–7876) n = 57/58	1026 (112–6903) n = 76/78		- 27 (−389 to 336)
WBC (absolute cell count)	10079 (1700–35800) n = 58/58	9812 (3800–24900) n = 77/78		268 (−1456 to 1991)
Hgb (gm/dL)	13.4 (8.5–17.9) n = 58/58	12.8 (6.7–18) n = 77/78		0.63 (−0.13 to 1.4)
Creatinine (mg/dL)	1.50 (0.5–15.9) n = 58/58	1.84 (0.3–10.2) n = 76/78		−0.34 (- 1.1 to 0.39)
ALT (U/L)	62 (17–160) n = 58/58	69 (10–430) n = 75/78		−7.1 (−29 to 15)
CRP (mg/L)	228 (35–481) n = 58/58	204 (5–798) n = 77/78		24 (−23 to 72)
Ferritin (ng/mL)	1745 (218–9295) n = 56/58	1670 (47–17933) n = 63/78		75 (−719 to 868)
LDH (U/L)	1418 (366–3521) n = 55/58	1472 (368–9614) n = 71/78		−54 (−426 to 318)
Procalcitonin (ng/mL)	0.58 (0.02–3.63) n = 47/58	1.54 (0.04–29.9) n = 51/78		−1.5 (- 3.2 to 0.12)
INR	1.9 (0.9–15) n = 43/58	1.5 (1–15) n = 64/78		0.40 (−0.47 to 1.3)

**Subsample of hooded patients used for portion of study which excluded 10 existing hospitalized patients whose final outcomes on intubation and mortality were available at the end of the study period.

[a] Independent t-test used for analysis.

[b] number of subjects with the comorbidity over the total number of subjects in the sample where information on the comorbidity was available in the record.

[c] All percentages are given as percent of the total column sample irrespective of missing data.

[d] Events < 5 in at least one cells.

Table 3a

Effect of Mechanical Ventilation on Mortality rates in the Total Sample (N = 136).

	Total Intubated	Total Not Intubated	Mortality in the Intubated patients	Mortality in the Non - Intubated Patients	OR 95%CI	p-value Pearson Chi squared
Total Sample	60/136 (44.1%)	76/136 (55.9%)	45/60 (75%)	45/76 (59.2%)	2.07 (0.98 to 4.34)	p = 0.053

Table 3b

Mechanical ventilation and mortality rates in the intervention (58/136) and control cohort (78/136) *.

Outcomes Total Sample (N = 136)	Intervention cohort (n_1 = 58)	Control cohort (n_2 = 78)	Difference (%)	OR 95%CI	Mean Difference (Days) 95%CI*	p-value Pearson Chi-squared	p-value Ind. T - test
Mechanical Ventilation	23/58 (39.7%)	37/78 (47.4%)	7.7%	0.73 (0.37 to 1.5)		0.37	
Mortality	36/58 (62.1%)	54/78 (69.2%)	7.1%	0.73 (0.36 to 1.5)		0.38	
Length of Stay	12.62 days	10.13 days			2.49 (−0.37 to 5.35)		0.90

Hypotheses*.

Ho: There is no difference in the MV rates, and/or mortality rates, and/or hospital length of stay in COVID-19 patient receiving oxygen hoods who failed on conventional high-flow oxygen delivery systems; as compared to those maintained on high-flow oxygen delivery systems OR failing on high-flow oxygen delivery systems AND requiring mechanical ventilation, under normobaric conditions.

Ha: There is a difference in the intubation rates, and/or mortality rates, and/or hospital length of stay in COVID-19 patient receiving oxygen hoods who failed on conventional high-flow oxygen delivery systems; as compared to those maintained on high-flow oxygen delivery systems OR failing on high-flow oxygen delivery systems AND requiring mechanical ventilation, under normobaric conditions.

3.5. Subgroup analyses

A. Subgroup Analysis Excluding Any Patients Who Received Convalescent Plasma Antibodies From Both Cohorts (Excluded 21-Intervention and 2-Control Patients). Table 4a

Mechanical ventilation rates were observed to be higher in the control 36/76 (47.4%) as compared to the intervention cohort 23/37 (40.5%), a difference of 6.9% or a 24% reduction in MV in the group receiving oxygen hoods, this reduction was not found to be statistically significant, OR 95%CI 0.76 (0.34–1.7).

Mortality rates were observed to be higher in the control 52/76 (68.4%) as compared to the intervention cohort 23/37 (62.2%), a difference of 6.2% or a 24% reduction in mortality in the group receiving oxygen hoods, this reduction was not found to be statistically significant, OR 95%CI 0.76 (0.33–1.7).

The mean length of hospitalization was observed to be 10.57 days in the intervention and 10.36 days in the control group. The controls demonstrated a slightly shorter LOS, than the group receiving oxygen hoods, this reduction was not found to be statistically significant, 0.21 days 95%CI (−2.6 to 3.0).

B. Mechanical Ventilation Rates after Reassignment of DNI/DNR Patients who Expired AND were never Mechanically ventilated as Mechanically Ventilated; with the Exclusion of Patients Receiving Convalescent Plasma Antibodies in both cohorts. Table 4b

Intubation rates were observed to be higher in the control 49/76 (69.7%) as compared to the intervention cohort 24/37 (63.9%), a difference of 5.8% or a 23% reduction in MV in the group receiving oxygen hoods, these reductions were not found to be statistically significant, OR (95%CI) 0.77 (0.33–1.8).

3.6. Logistic regression analysis (using forward and backward stepwise Likelihood Ratio)

A logistic regression analysis was conducted to investigate the effects of prognosticators reported by the CDC and other sources that may be predictive of outcomes in COVID-19 patients [3,14,19]. The likelihood that predictor covariates effect rates of mechanical Ventilation and/or mortality rates were investigated. The intervention oxygen hoods, along with the covariates age, BMI, gender, D-Dimer level, lymphocyte count, chronic lung disease, cardiovascular disease, chronic kidney disease, immunosuppression, and DM were investigated [3,14].

Patients who expired but whose status was DNI/DNR were reassigned as having been mechanically ventilated when investigating predictors of mechanical ventilation for both cohorts. This was done since the patients failing conventional oxygen delivery systems would have been placed on mechanical ventilation had their status not been DNI/DNR.

None of the covariates were identified as predictor variables for mechanical ventilation or mortality in the model except age. Age was identified when using logistic regression with Forward stepwise Likelihood Ratio. Backward stepwise regression failed to identify any of the variables including age as predictors of mortality or mechanical ventilation. Age remained a predictor of mechanical ventilation and mortality in subgroup analysis when patients receiving convalescent plasma antibodies were excluded.

The logistic regression model (Model 1) predicting mechanical ventilation was found to be statistically significant χ^2 = 6.618, p = 0.010. The model explained 8.8% (Nagelkerke R^2) of the variance in mechanical ventilation and correctly classified 60/99 (60.6%) of cases. 37 cases included missing data due to nonreporting of one or more of the covariates other than the predictor variable hood status or the outcome variable of interest mechanical ventilation. The model predicted an OR = 1.036 or a 3.6% increase in risk of mechanical ventilation for every one-year of age within the studied age range. See Table 4c.

The logistic regression model (Model 2) predicting mortality was found to be statistically significant χ^2 = 10.623, p = 0.001. The model explained 13.8% (Nagelkerke R^2) of the variance in mortality and correctly classified 62/99 (62.6%) of cases. 37 cases were missing data due to nonreporting of one or more of the covariates other than the predictor variable hood status or the outcome variable of interest mortality. The model predicts an OR based on age of 1.047 or a 4.7% increase in risk of mortality for every year within the studied age range, see Table 4d.

4. Discussion

The use of hyperbaric oxygen hoods prevented immediate/imminent intubation and mechanical ventilation (MV) in the short-term in 58 out of the 58 COVID-19 patients receiving oxygen hoods with a mean improvement in oxygen saturation of 8.8%, 95%CI (7.8–9.8). This intervention affords healthcare practitioners an effective alternative

Table 4a

Subgroup Analysis Excluding Any Patients who Received Convalescent Plasma Antibodies from both cohorts (21-Intervention and 2-Control Convalescent Plasma Recipient Patients Excluded).

Outcomes N = 113	Intervention cohort (n_1 = 36)	Control cohort (n_2 = 75)	Difference (%)	OR 95%CI	Mean Difference (Days) 95%CI*	p-value Pearson X^2 chi-squared	p-value Ind. T - test
Mechanical Ventilation	23/37 (40.5%)	36/76 (47.4%)	6.9%	0.76 (0.34 to1.7)		0.49	
Mortality	23/37 (62.2%)	52/76 (68.4%)	6.2%	0.76 (0.33 to 1.7)		0.51	
Length of Stay	10.57 days	10.36 days			0.21 (−2.6 to 3.0)		0.88

Table 4b

Subgroup Analysis – Mechanical Ventilation Rates by Reassignment of DNI/DNR Patients that Expired and Never Intubated as Intubated And Excluding Patients Receiving Convalescent Plasma Antibodies in both cohorts.

Outcomes N = 113	Intervention cohort (n_1 = 37)	Control cohort (n_2 = 76)	Difference	OR 95%CI	p-value Pearson χ^2
Mechanical Ventilation	24/37 (63.9%)	49/76 (69.7%)	5.8%	0.77 (0.33 to 1.8)	0.54

Table 4c

Model 1 Predictors for Intubation/Mechanical Ventilation (MV) using Logistic Regression (Forward Stepwise Likelihood Ratio with Reassignment of DNI/DNR Patients that Expired as Intubated/Mechanically Ventilated).

Model 1 Variables*	Coefficient (B)	Standard Error (SE)	Wald Statistic	Sig.	Exp (B)	Exp (B) 95%CI
Age	0.035	0.014	6.097	0.014	1.036	(1.007 to 1.07)
Constant	−1.910	0.982	3.785	0.052	0.148	

Log Form: Log OR = −1.910 + 0.035*Age.
Exponential Form: $P = [e^{(-1.190+0.035*Age)}]/[1 + e^{(-1.190+0.035*Age)}]$.

Table 4d

Model 2 Predictors for Mortality using Logistic Regression (Forward Stepwise Likelihood Ratio).

Model 2 Variables*	Coefficient (B)	Standard Error (SE)	Wald Statistic	Sig.	Exp (B)	Exp (B) 95%CI
Age	0.046	0.015	9.213	0.002	1.047	1.02 to 1.08
Constant	−2.665	1.037	6.600	0.010	0.070	

Log Form: Log OR = −2.665 + 0.046*Age.
Exponential Form: $P = [e^{(-2.665+0.046*Age)}]/[1 + e^{(-2.665+0.046*Age)}]$.

*The logistic regression model utilizing age applied as a predictor for intubation in subgroup analysis upon re-assigning of DNI/DNR patients that expired as intubated/mechanically ventilated whether including (model 1) or excluding (model 2) patients receiving convalescent plasma antibodies.

** The logistic regression model utilizing smoking status applied as a predictor for mortality in subgroup analysis whether including (model 3) or excluding (model 4) patients receiving convalescent plasma antibodies.

high-flow oxygen delivery system in these hypoxic COVID-19 patients who are failing conventional high-flow oxygen delivery systems.

Intubation and mechanical ventilation of hypoxic COVID-19 patients has been associated with high mortality, approaching 76.4–97.2% [3]. Mortality associated with intubation/MV in the total sample was consistent with reported estimates and was observed to be 75%, OR 95% CI 2.07 (0.98 to 4.34), which was not found to be statistically significant. Though the confidence interval nearly reached the threshold of significance.

Oxygen hoods may afford additional time for existing life-saving measures and evolving medical interventions to work and for more resources to become available, potentially delaying or foregoing the need for intubation and mechanical ventilation.

Effect size reductions for in-hospital mechanical ventilation and mortality rates with oxygen hoods were consistently observed. The effects were relatively small 7.7% and 7.1% respectively but were not found to be statistically significant.

These reductions were also observed in subgroup analyses. Subgroup analysis included reassignment of DNI/DNR patients who expired to the intubation/MV outcome and controlling for patients receiving convalescent plasma antibodies. The reductions in mechanical ventilation and mortality were observed favoring the use of the oxygen hood but were

not found to be statistically significant.

Mechanical ventilation and mortality rate reductions have been observed by other researchers to be significant with the use of similar oxygen hoods/helmets in patients with ARDS [7]. During a pandemic small effect sizes may impact large numbers of patients, if the reductions are true effects.

4.1. Limitations

The evaluation for differential levels of comorbidities and potential confounders, including the use of logistic regression analysis to predict intubation/mechanical ventilation and mortality, did not demonstrate statistically significant differences between the intervention and control cohorts with the exception of DM, CKD. Age was observed in the logistic regression model to be predictive of mortality in COVID-19 patients consistent with similar findings by other researchers [6]. The analysis did not support other covariates as predictors of mechanical ventilation or mortality rates.

Reasons that could have explained not reaching the threshold for significance despite consistently observed reductions for in-hospital mechanical ventilation and mortality rates include the following.

Despite the observed balance in predictor covariates for both

cohorts; Covid-19 respiratory disease severity was not considered balanced between the intervention and control cohorts and is a limitation in this study. Efforts were made to choose a comparable control group, using the requirement for conventional high-flow oxygen delivery systems as a marker of respiratory disease severity. However, except for the control patients who had already failed on these systems and were subsequently intubated, there were control patients in this group who did not fail on these conventional high-flow oxygen delivery systems remaining on them throughout hospitalization and who never required mechanical ventilation.

This distinction is important as in contrast every patient receiving the oxygen hoods was failing on these same conventional high-flow oxygen delivery systems. This critical distinction supports the assertion that the intervention cohort patients demonstrated a higher level of critical illness and severity of respiratory failure as compared to the control cohort; yet trends demonstrating observed reductions of intubation and mortality rates were consistently lower in the intervention as compared to the control cohort despite this limitation.

The reductions in intubations and mortality may have risen to the threshold level of significance had the control group been balanced in respiratory disease severity. However, this would have decreased the size of the control cohort in the sample.

A larger sample size would have improved power and reduced the likelihood of a type-2 error. The national emergency created by the pandemic made it difficult to gauge exactly how many patients would be available to study. The gravity of the COVID-19 pandemic and the positive results in improved patient oxygenation warranted reporting these findings. Lower effect sizes than those used for our sample size calculation could be considered clinically significant in the absence of a pandemic.

The oxygen hood is a novel alternative high-flow oxygen delivery system to use with hypoxic COVID-19 patients presenting with impending respiratory failure, however nursing and respiratory staff were initially unfamiliar with its use. Despite oxygen hood training, equipment inexperience could have led to premature discontinuation of the hood in favor of a returning prematurely to conventional high-flow O_2-delivery systems, or an incorrect presumption that the oxygen hoods were titratable like conventional high-flow oxygen delivery systems when they are not. These factors could have led to suboptimal use of oxygen hood systems in COVID-19 patients further confounding the study.

5. Conclusion

The implementation of the oxygen hood demonstrated significant improvement in O_2-saturation above that of conventional high-flow oxygen delivery systems and prevented immediate/imminent intubation and mechanical ventilation in the short-term; potentially allowing additional time for other treatments to work.

The observed intubation and mortality effect sizes may have been larger between the intervention and control cohorts if not for the limitations discussed. Larger effect sizes could have reached the level of significance with the sample size used in the study reducing the probability of type 2 error. Longer-term reductions in the mechanical ventilation and mortality rates with use of similar oxygen hoods among ARDS patients has been observed by other researchers and found to be significant, this could be similar for hypoxic COVID-19 patients [7].

The oxygen hood is a safe, reliable, and an effective form of oxygen delivery which may reduce mechanical ventilation and mortality rates. Their use should be considered in treating COVID-19 patients and possibly other patients with hypoxia failing on conventional high-flow oxygen delivery systems to prevent mechanical ventilation.

CRediT authorship contribution statement

David Dayya: Data curation, Formal analysis, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis, Conceptualization, Study concept and design, Funding acquisition, Formal analysis, Data curation, Acquisition, analysis, or interpretation of data, All authors in, the acquisition of data, Writing - original draft, Drafting of the manuscript, Critical revision of the manuscript for important intellectual content, Statistical analysis, Administrative, technical, or material support, Supervision, Study supervision. **Owen J. O'Neill:** Data curation, Formal analysis, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis, Conceptualization, Study concept and design, Funding acquisition, Formal analysis, Data curation, Acquisition, analysis, or interpretation of data, All authors in, the acquisition of data, Writing - original draft, Drafting of the manuscript, Critical revision of the manuscript for important intellectual content, Statistical analysis, Administrative, technical, or material support, Supervision, Study supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rmed.2021.106312.

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