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ORIGINAL RESEARCH ARTICLE

STUDY OF OXYGEN DELIVERY METHODS USE IN THE COVID-19 PATIENTS

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ABSTRACT

Background: The oxygen crisis globally during the Corona virus disease-19 (COVID-19) pandemic reflected the need of appropriate and economic use of oxygen in its management. There is scarce report of the use of different oxygen delivery methods (ODMs) in COVID-19 patients in our region.

Methods: This was a hospital-based observational study conducted from July 2021 to October 2021. We studied various ODMs used by 100 COVID-19 patients, aged 18 years or above admitted to Chitwan Medical College and Teaching Hospital during July to October 2021 and the trend of how the ODMs changed during the hospital stay. Data analysis was done by SPSS version 20 for Windows. Fisher's exact and Kruskal Wallis tests were used to analyze the data of the participants.

Results: In our study, oxygen supplementation at presentation using nasal cannula was required by 74% of patients, face mask by 13%, Venturi mask 34%, non-rebreathing mask 25%, high-flow nasal cannula 27%, non-invasive ventilation 6%, and invasive mechanical ventilation by 21%. There was significant difference in the use of ODMs at presentation among the moderate, severe and critical COVID-19 groups (P<0.001). There was a wide range of switching between various ODMs during the treatment course.

Conclusions: Nasal cannula was the most common ODM followed by venturi devices and invasive mechanical ventilation. Despite varying oxygen flow requirements, aerosol risks, merits and limitations of different ODMs, they can be appropriately used in various COVID-19 management situations. Besides inspired oxygen concentration and oxygen flow, patients' condition, tolerance and availability of the resource also affected the choices of ODMs to achieve the correction of hypoxemia.

INTRODUCTION

Pneumonia and respiratory failure are common complications and causes of death in COVID-19 disease.[1,2] COVID-19 pneumonia and its severity are diagnosed by clinical and radiological assessment, and oxygen saturation.[3,4] From the beginning of COVID-19 pandemic, the value of oxygen in its management has been realized. The oxygen crisis globally during the COVID-19 pandemic affecting both industrialized and non-industrialized countries has reflected the need of appropriate use of oxygen in the management of COVID-19.[5-7] Various methods of oxygen delivery devices are available, each of which has different oxygen flow requirement, aerosol risk, merits and limitations.[8-12] There is scarce report of the use of different oxygen delivery methods in our region. The study was aimed to assess the various oxygen delivery devices used by the COVID-19 patients and the trend of how the methods of oxygen delivery changed during the course of hospital stay.

METHODS

This was a hospital-based observational study conducted from July 2021 to October 2021 in the COVID intensive care unit of Chitwan Medical College and Teaching Hospital (CMCTH), Bharatpur Nepal. COVID 19 infection was diagnosed from reverse transcription polymerase chain reaction (RT-PCR) of oro- and nasopharyngeal swabs. The patients were managed by the pulmonary and critical care unit. Covid-19 adult patients age 18 years and above admitted in the COVID intensive care unit (ICU) for more than 24 hours requiring oxygen supplementation were included in our study. Patients who were already put on mechanical ventilators prior to ICU admission at CMCTH were excluded. Written informed consent was taken from the patients. Ethical approval was taken from the CMCTH Institutional Review Board.

Patients with clinical signs of pneumonia with respiratory rate >30 breaths per min, SpO2 <90% on room air, or signs of severe respiratory distress (accessory muscle use and inability to complete full sentences) were included in the severe group and patients with acute respiratory distress syndrome, sepsis, shock or other conditions requiring life-sustaining therapies in critical illness group.[3] Hospitalized patients without such signs, with SpO2 on admission between 90 – 94% were included as moderate (non-severe) illness group in our study. We studied the various oxygen delivery devices used for the patients. Comparison between the different severity groups were done. The trend of how the methods of oxygen delivery changed during the course of hospital stay was observed.

All data were recorded in the proforma by the principal investigator. Data entry and analysis was done by SPSS version 20 for Windows. Median values and range were calculated. Fisher's exact and Kruskal Wallis tests were used to analyze the data of the participants. P value <0.05 was considered statistically significant.

RESULTS

The median age of the patients was 64.5 years and almost two-third of them were males. At least one comorbidity was present in more than two-third of the patients, the most common being hypertension followed by diabetes and chronic obstructive pulmonary disease. Almost half of the patients had critical COVID-19 (Table 1).

Table 1: Demographic and clinical characteristics of the patients (n = 100)

Characteristics	Frequency (%)
Age (years), median (IQR)	64.5 (17 – 96)
Gender, n (%)	
Male	66 (66.0)
Female	34 (34.0)
Duration of symptoms (days), median(IQR)	5 (1–20 days)
Comorbidity present, n (%)	70 (70.0)
Comorbidity, n (%)	
HTN	37 (37.0)
T2DM	25 (25.0)
COPD	16 (16.0)
COVID-19 severity, n (%)	
Moderate	20 (20.0)
Severe	36 (36.0)
Critical	44 (44.0)

Table 2: The median duration of O2 delivery methods used and maximum flow rate of oxygen of each modality among different severities of COVID-19

O2 delivery methods	Moderate COVID-19 (n = 20)	Severe COVID-19 (n = 36)	Critical COVID-19 (n = 44)
Nasal prong (NP)			
Max flow rate (L/min),	3	3.5	4
Median duration (days), median (range)	3 (1 – 5)	2 (1 - 24)	2 (0.5 - 8)
Simple face mask (FM)			
Max flow rate (L/min),	6	6	10
Median duration (days), median (range)	1 (1 – 2)	1 (0.5 – 3)	1 (1 – 2.5)
Venture face mask (VM)			
Max flow rate (L/min), median	8	8	12
Duration (days), median (range)	2.5 (2 -3)	2 (1 – 10)	1 (0.5 – 6)
Non-rebreathing mask (NRBM)			
Max flow rate (L/min)	-	15	15
Duration (days)		1	1.75 (0.5 – 9)
High flow nasal cannula (HFNC)			
Max flow rate (L/min)	-	60	60
Duration (days)		3.5 (2 – 5)	2 (0.5 – 9)
Non-invasive ventilation (NIV)			
Max flow (L/min)	-	60	60
Duration (days)		1.75 (0.5 – 3.0)	2 (1 – 4)
Endotracheal tube (ET)			
Max flow rate (L/min)	-	-	60
Duration (days)			4 (0.5 – 15)

The median duration of O2 delivery devices used and flow rate of oxygen of each modality among different severities of COVID-19 is shown in Table 2.

Out of the total 100 patients, nasal cannula was used by 74% of the patients during their treatment, face mask by 13%, Venturi mask 34%, non-rebreathing mask (NRBM) 25%, high-flow nasal cannula (HFNC) 27%, non-invasive ventilation (NIV) 6%, and invasive mechanical ventilation by 21% (Table 3). Admission oxygen saturations (SpO2) were significantly different among the moderate, severe and critical COVID-19 with progressively lower values in severe and critical ones (P<0.001) (Table 3). There was significant difference in the use of oxygen delivery devices among the moderate, severe and critical COVID-19 groups (P<0.001). In moderate COVID-19 patients, nasal cannula, simple face mask and Venturi mask were only the O2 delivery devices used and higher oxygen delivery methods like NRBM, HFNC, NIV, and invasive mechanical ventilation were also used in critical COVID-19 and almost half of the critical patients required mechanical ventilation (Table 3).

Table 4 showed the comparison of different patient variables between various forms of oxygenation method. There were significant differences in the age (P=0.01) and gender (P=0.02) of the patients, presence of comorbidities (P=0.04) and hospital stay (P=0.002) among the various forms of oxygen delivery devices used.

Table 3: Admission SpO2 and oxygen delivery methods used during treatment in different clinical severities of COVID-19

Variables	Moderate COVID-19 (n = 20)	Severe COVID-19 (n = 36)	Critical COVID-19 (n = 44)	P-value
Admission SpO_2%, median (range)	91 (85 – 94)	87 (59 – 91)	80 (31 – 95)	<0.001*
O2 delivery methods used, n (%)				
NC	20 (100.0)	34 (94.4)	20 (45.5)	<0.001**
FM	3 (15.0)	5 (13.9)	5 (11.4)	
VM	2 (10.0)	7 (19.4)	25 (56.8)	
NRBM	-	1 (2.8)	24 (54.5)	
HFNC	-	2 (5.6)	25 (56.8)	
NIV	-	2 (5.6)	4 (9.1)	
MV	-	-	21 (47.7)	

* Kruskal Wallis test, ** Fisher's exact test

Table 4: Comparison of different patient variables between various forms of oxygen delivery devices

Variables	NC (n=36)	FM (n=8)	VM (n=10)	NRBM (n=7)	HFNC (n=16)	NIV (n=2)	MV (n=21)	P value
Age (years), median (range)	57 (26-94)	55.5 (24-89)	61.5 (25-72)	75 (64-88)	71 (42-96)	81 (74-88)	66 (17-85)	0.01*
Gender, n (%)								
Male	24	3	10	3	11	0	6	0.02
Female	12	5	0	4	5	2	15	
Duration of symptoms (days), median (range)	5(1-5)	6(3-12)	6(3-10)	5(2-7)	5(2-8)	3	7(2-20)	0.39*
Comorbidity present, n (%)	23 (63.9)	6 (75.0)	6 (60.0)	7 (100.0)	11 (69.8)	2 (100.0)	15 (71.4)	0.04
Hospital stay (days), median (range)	6(1-18)	3.5 (2-9)	9(1-42)	5(3-12)	8.5 (1-17)	4 (3-5)	9 (3-26)	0.002*

* Kruskal Wallis test, in the remaining Fishers's exact test was used.

NC: Nasal cannula, FM: Simple face mask, VM: Venturi face-mask (VM), NRBM: Non-rebreathing mask, HFNC: High-flow nasal cannula, NIV: Noninvasive ventilation, MV: Mechanical ventilation

Table 5 showed the oxygen delivery method used just prior to the final oxygen delivery devices used by the patients. Before the patients were put on invasive mechanical ventilation, three patients were on Venturi mask, five patients each on NRBM and NIV, and nine patients were on HFNC. Before the patients were on HFNC, two patients were on nasal cannula, eight on Venturi mask and six on NRBM. Similarly, before applying NRBM, two patients were on nasal cannula and five on Venturi mask. Before applying NIV, two patients were on nasal cannula and before Venturi mask, nine patients were on nasal cannula. There was a wide range of switching from various oxygen delivery devices to the final oxygen delivery device used by the patients (Table 5). Nine patients on nasal cannula were switched to Venturi mask, and two patients each on to NRBM, HFNC, and NIV. Similarly from Venturi mask, five patients were switched to NRBM, eight to HFNC, and three to invasive mechanical ventilation. Five of NIV and nine of HFNC were switched to invasive mechanical ventilation. We found that changing oxygen delivery devices to correct hypoxemia in COVID pneumonia could not always be based on their inspired oxygen concentration or oxygen flow; as some patients were changed from nasal cannula to Venturi mask while some to NRBM or NIV or HFNC. This also depended on patients' conditions and preference or tolerance to the device, and also on the availability of the resource.

Table 5: Oxygen delivery methods (ODMs) used just prior to the final ODMs used by the patients

ODMs used before the final ODMs	Final oxygen delivery methods (ODMs) used by the patients				
	VM	NRBM	HFNC	NIV	MV
NC	9	2	2	2	-
FM	-	-	-	-	-
VM	-	5	8	-	3
NRBM	-	-	6	-	5
NIV	-	-	-	-	5
HFNC	-	-	-	-	9

NC: Nasal cannula, FM: Simple face mask, VM: Venturi face-mask (VM), NRBM: Non-rebreathing mask, HFNC: High-flow nasal cannula, NIV: Noninvasive ventilation, MV: Mechanical ventilation.

DISCUSSION

In this research, various forms of oxygen delivery devices used in COVID-19 pneumonia of 100 patients were studied. There was significant difference in the use of oxygen delivery devices among the moderate, severe and critical COVID-19 groups. Nasal cannula was the most commonly used oxygen delivery devices followed by Venturi masks in this study. About one-fourth of the patients required invasive mechanical ventilation. In moderate COVID-19 patients, nasal cannula (NC), simple face mask (FM) and Venturi mask (VM) were only the O2 delivery devices used and higher oxygen delivery methods like non-rebreathing mask (NRBM), high-flow nasal cannula (HFNC), non-invasive ventilation (NIV), and mechanical ventilation (MV) were also used in critical COVID-19. Almost half of the critical patients required MV. There were significant differences in the age and gender of the patients, presence of comorbidities and hospital stay between various forms of oxygen delivery devices used. On analysis of the data of oxygen delivery method used just prior to the final oxygen delivery device used by the patients, there was a wide range of switching from various oxygen delivery devices to the final oxygen delivery device used by the patients. Each of the different oxygen delivery devices used has different oxygen flow requirement, aerosol risk, merits and limitations (Table 6).[8-12]

Oxygen is an effective treatment for hypoxemia.[10]. Clinical severity of COVID-19 pneumonia is guided by the oxygen saturation.[3,4] However, many patients of COVID-19 are also noted to have severe hypoxia without any breathing trouble; such hypoxia is called as silent or happy hypoxia.[13] Thus the oxygen saturation of the patients are routinely assessed to look for hypoxia. Various mechanisms like limitations of pulse oximetry, shift in oxygen dissociation curve, role of angiotensin-converting enzyme 2, and thrombi in the pulmonary vasculature have been considered for the explanation of silent hypoxia.[13] Silent hypoxia needs to be considered while assessing any COVID 19 patients.

Aggressive oxygen therapy to correct hypoxia is critical for the successful treatment of COVID-19 patients and the reduction of mortality. Titrating oxygen is recommended to a target peripheral oxygen saturation (SpO2) of ≥94% during initial resuscitation and ≥90% in non-pregnant adults and ≥ 92–95% in pregnant women for maintenance oxygenation.[3] For those at risk of hypercapnic respiratory failure, disease-specific or patient-specific target range of oxygen saturation may need to be considered.[10] For patients with COVID-19, supplemental oxygenation with a low flow system via nasal cannula is usually initiated. Apart from the properties mentioned in Table 6, the other advantages of nasal cannula include adjustable flow to give wide oxygen concentration, patient preference, no claustrophobic sensation, not taken off to eat or speak and less likely to fall off, cheaper, and no risk of rebreathing of carbon dioxide and other limitations include may cause nasal irritation or soreness and actual concentration of oxygen cannot be predicted.[10] Higher flows of oxygen may be administered using a simple face mask, Venturi face mask, or others (Table 6), but as flow increases, the risk of dispersion also increases, augmenting the contamination of the surrounding environment and staff.[8,9,11]

In our study, on analysis of the data of oxygen delivery method used just prior to the final oxygen delivery device used by the patients, there was a wide range of switching from various oxygen delivery devices to the final oxygen delivery device used by the patients. We found that changing oxygen delivery devices to correct hypoxemia in COVID pneumonia could not always be based on their inspired oxygen concentration or oxygen flow; as some patients were changed from nasal cannula to Venturi mask while some to NRBM or NIV or HFNC. This also depended on patients' conditions and preference or tolerance to the device, and also on the availability of the resource. Correction of hypoxemia irrespective of the mode of delivery of oxygen appeared more important for favorable outcome in patients with COVID pneumonia.

As patients' condition deteriorate, higher amounts of oxygen are needed. Options at this point in COVID-19 patients are high-flow oxygen via nasal cannula (HFNC) or the initiation of noninvasive ventilation (NIV). Both modalities have been used variably. In patients with COVID-19 who have acute hypoxemic respiratory failure and higher oxygen needs than that low flow oxygen can provide, experts suggest that noninvasive modalities, like NIV and HFNC, may be used rather than proceeding directly to intubation. In our study, only 6% of the total patients used NIV during their course while 27% used HFNC; HFNC was used four to five times than NIV. NIV has been used for the acute exacerbation of COPD and acute congestive heart failure.[11] However, in severely symptomatic patients, its use may be limited as it may only delay intubation and lead to mortality and the lack of properly fitting masks and accessories preclude the use of NIV in many settings.[11] A trial that compared HFNC oxygen, standard oxygen via face mask and face mask NIV in 310 patients with acute hypoxemic respiratory failure, reported that the intubation rate was significantly lower with HFNC oxygen than with standard oxygen devices or NIV among patients with PaO2/FiO2 ≤ 200 mmHg at enrollment and, for the whole group (patients with PaO2/FiO2 ≤ 300 mmHg), patients managed with HFNC had improved survival. There were no differences in outcomes between NIV and standard oxygen devices used.[14] A sub-study examined the practice of NIV use in ARDS of LUNGSAFE STUDY reporting that NIV was associated with higher ICU mortality in patients with a PaO2/FiO2 < 150 mmHg.[15]

In comparison to non-invasive ventilation (NIV), HFNC is more comfortable and easily tolerated, in addition to its simplicity for application.[8] Additionally, HFNC reduces intubation rates in acute respiratory failure, while NIV may increase the intubation rate or delay the tracheal intubation. Considering the high rate of pneumothorax in COVID-19 patients, HFNC may be a better choice than NIV.[8] HFNC should be used before NIV in critically ill COVID-19 patients; although more studies are needed to confirm this. If NIV is used, it should be limited to short periods with close monitoring of pulmonary failure and decision for early tracheal intubation for invasive ventilation.[8] The major concern of HFNC is that it may increase virus aerosol spreading. The risk always, though, exists even without the use of HFNC. The meaningful effort is to instruct the patients to wear surgical masks during HFNC treatment to reduce the risk of virus transmission.[8]

Table 6: Properties, relative oxygen (O2) flow requirement and aerosol risk of commonly used O2 delivery devices[8-12]

Oxygen delivery devices	Inspired oxygen percentage	Oxygen flow	Number of large O_2 cylinders required per day*	Aerosol risk**	Comment
Nasal cannula	24 to 40%	1 to 4 L/min	0.23 to 0.95	+ to ++	• Comfortable and acceptable • May not work if nose is severely congested or blocked.
Simple face mask	35 to 60%	5 to 10 L/min	1.19 to 2.37	++	• Should fit over the nose and mouth • Requires humidification when O_2 flow is above 6 litres per minute
Venturi Mask (VM)	24, 28, 31, 35, 40 and 60%	2 to 20 L/min	0.47 to 4.73	++ to +++	• Gives an accurate O_2 concentration to the patient • 24% and 28% VM are suited to those at risk of carbon dioxide retention • Higher flow rate is required if the respiratory rate is >30 • OxyMask may work like VM at lower oxygen flow rate
Non-rebreathing mask (NRBM)	60 to 95%	10 to 15 L/min	2.37 to 3.55	+	• Mask with a reservoir bag attached to O2 supply with exhalation valves not allowing exhaled or outside air to enter in the bag • Usually in emergency situations requiring high O2 concentration • Patient can only breathe from oxygen supply and disruptions in airflow can lead to suffocation. • Can deliver high-dose oxygen if mask fits well and airflow more than three times of minute ventilation
Partial rebreathing mask	50 to 80%	10 to 12 L/min	2.37 to 2.85	++	• Does not have valves allowing the patient to rebreathe some expired air • Used to conserve oxygen, for instance during transport
High-flow nasal cannula (HFNC)	>80 to 100%	10 to 70 L/min	2.37 to 16.55	+++	• Nasal reservoir should fit well • Patient should wear surgical/N95 mask and breathe nasally
Non-invasive ventilation***	>80%	60 L/min****	14.25	+++	• Skin breakdown is a side effect • Benefit to risk ratio seems lower than HFNC that may be preferred to be used before NIV
Mechanical ventilation	Any inspired oxygen concentration	60 L/min	14.25	+/- (+++++ during intubation)	• Invasive method • Requires tracheal intubation • Ensure proper cuff seal • Use close suctioning

* This is an approximate calculation based on oxygen flow required and the volume (48 liter), tank constant (3.14), filling pressure or gauge pressure (150 kg-f/cm^2 = 2133.5015 psi) and safe residual pressure (200 psi) of the large oxygen cylinder. The number of small oxygen cylinder (with volume 10 liter, tank constant 0.28, filling pressure or gauge pressure 150 kg-f/cm2 or 2133.5015 psi, and safe residual pressure 200 psi) is approximately equal to the number of large cylinder multiplied by 11.25.

** Increases with cough and sneeze

*** Primarily includes continuous positive airway pressure (CPAP) or Bi-level positive airway pressure (BiPAP)

**** Many portable ventilators may deliver lower flow e.g. up to 10 or 15 L/min

Note: Uncontrolled oxygen delivery may promote hypercapnia in patients with chronic obstructive pulmonary disease.

When using NIV and HFNC, oxygenation and breathing patterns must be closely monitored, and delay in ET intubation should be avoided.[16] In our study, only six patients used NIV during their course while 27 patients used HFNC. Almost all patients were encouraged for prone position as much as tolerated, which also seemed to improve the oxygen saturation and outcome in most severe and critical cases.

Our study has several limitations. The sample size was small. There was no correlation with arterial blood gas analysis and imaging tests done in the study. Outcome was also not studied as there are multiple factors to be considered which could be related with the outcome. Individual patient factors (like older age, male sex, deprivation, obesity, diabetes, and preexisting lung disease), social-demographic and vulnerabilities factors (like socioeconomic status, racial/ethnic minority status, household composition, and environmental factors), other population-demographic factors (like higher proportions of the population living in urban areas, countries with lower reduction in mobility at the beginning of the pandemic and countries having more infected people when closing borders), and public health factors (like health expenditure, public health measures and the number of physicians) are associated with COVID-19 morbidity and mortality.[17-20]

Apart from those factors, prior infection with COVID-19 infection, vaccination against infection, use of timely appropriate anti-viral and anti-inflammatory medications, and management of the complications of the medications and therapeutics used also affect the morbidity and mortality associated with COVID-19 infection

CONCLUSION

Among various forms of oxygen delivery devices studied, nasal cannula was the most commonly used oxygen delivery devices followed by venturi masks. There was significant difference in the use of oxygen delivery devices among the moderate, severe and critical COVID-19 groups. In moderate COVID-19 patients, nasal cannula, simple face mask and Venturi mask were only the O2 delivery devices used and higher oxygen delivery methods like non-rebreathing mask, high-flow nasal cannula, non-invasive ventilation, and mechanical ventilation were also used in critical COVID-19. Almost half of the critical patients required MV. There were significant differences in the age and gender of the patients, presence of comorbidities and hospital stay between various forms of oxygen delivery devices used. On analysis of the data of oxygen delivery method used just prior to the final oxygen delivery device used by the patients, there was a wide range of switching from various oxygen delivery devices to the final oxygen delivery device used by the patients. Apart from consideration of inspired oxygen concentration and oxygen flow, other factors like patients' condition preference and device tolerance and availability of the resource also affected the choices of device to achieve correction of hypoxemia. Different non-invasive oxygen delivery devices with their varying oxygen flow requirements, aerosol risks, merits and limitations can be appropriately used in various groups and conditions before using mechanical ventilation.

CONFLICT OF INTEREST: None

FINANCIAL DISCLOSURE: None

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