Case Report

Enhancing Pulmonary Function in COVID-19-Induced Acute Respiratory Distress Syndrome: A Case Study on the Efficacy of High-Flow Nasal Cannula Oxygenation Therapy

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Abstract

Background: Severe COVID-19 cases often lead to Acute Respiratory Distress Syndrome (ARDS), causing impaired gas exchange and necessitating oxygen therapy. High Flow Nasal Cannula (HFNC) has emerged as a potential treatment option for these patients.

Objective: This study aimed to evaluate the effectiveness of HFNC in improving oxygenation in COVID-19 patients with ARDS, potentially avoiding intubation.

Methodology: A case study was conducted on a 45-year-old female COVID-19 patient with obesity, who exhibited impaired gas exchange after nine days in the Intensive Care Unit (ICU). HFNC therapy was administered with oxygen flow rates of 30-60 liters/minute and FiO2 levels of 70-90%. Key parameters monitored included oxygen saturation, respiratory rate, shortness of breath, and the ROX index.

Results: Following HFNC therapy, the patient showed improved oxygen saturation, decreased respiratory rate, and reduced complaints of shortness of breath. The ROX index improved to >4.94, indicating successful treatment.

Conclusions: HFNC therapy appears to be an effective initial intervention for improving oxygenation in COVID-19 patients with ARDS, potentially preventing the need for intubation. Nurses play a crucial role in monitoring therapy success through assessment of various parameters, including SOFA score, ROX index, SpO2, respiratory rate, and reported shortness of breath.

Keywords: ARDS, COVID-19, HFNC, impaired gas exchange

Introduction

COVID-19 was declared a pandemic by the World Health Organization WHO in March 2020. Since December 2019, more than 760 million cases and 6.9 million deaths have been reported globally, though the actual figures are believed to be higher (WHO, 2023c). COVID-19 is a severe acute respiratory tract infection caused by a new type of coronavirus. This virus comes from the *Coronaviridae* family and is named SARS-CoV-2 (Peng, Ho and Hota, 2020; Ratre *et al.*, 2021). COVID-19 syndrome has several symptoms, ranging from asymptomatic mild to severe disease that can cause death. Common symptoms of COVID-19 include cough, fever, and shortness of breath. Other symptoms are weakness, malaise, respiratory problems, muscle pain, sore throat, anosmia (loss of smell), and ageusia (loss of taste) (Lovato, de Filippis and Marioni, 2020). In addition, 20% of COVID-19 patients can develop severe symptoms involving the lower respiratory tract with complications of acute respiratory distress syndrome (ARDS) (Parasher, 2021).

ARDS is a severe acute respiratory disorder characterized by poor oxygenation, pulmonary infiltrates, and acute onset (Diamond, M., Peniston Feliciano, H. L., & Sanghavi, 2023a). Based on the Berlin definition, there are several criteria for ARDS, including respiratory failure occurring within one week of the onset of the underlying disease; respiratory failure does not originate from abnormalities in heart function or excess fluid volume; on the chest x-ray, there is a picture of bilateral opacification that does not occur due to effusion, collapse or nodules; and finally, there is an acute onset of hypoxemia with PaO2/FiO2 values <300 mmHg. PaO2/FiO2 values of 201-300 mmHg are classified as mild ARDS, 101-200 mmHg as moderate ARDS, and <100 as severe ARDS (Ranieri *et al.*, 2012). At the microscopic level, ARDS is associated with capillary endothelial injury and diffuse alveolar damage. This condition of capillary endothelial injury and alveolar damage disrupts gas exchange between the alveoli and capillaries (Diamond, M., Peniston Feliciano, H. L., & Sanghavi, 2023b).

Most studies report that the mortality rate of COVID-19 patients with ARDS is very high. Most ARDS patients associated with COVID-19 die due to severe hypoxemia (Wang *et al.*, 2020a; Yang *et al.*, 2020; Zhou *et al.*, 2020). The primary nursing problem experienced by ARDS patients is gas exchange disorders caused by damage to the alveolar-capillary membrane (Huang *et al.*, 2018a). COVID-19 patients who develop ARDS usually require ventilation support as well as intensive care (Wang *et al.*, 2020b). However, limited resources during the pandemic crisis have resulted in the use of assisted ventilation or non-invasive oxygenation methods to prevent or delay patients from receiving mechanical ventilation. One method of non-invasive oxygenation assistance currently widely applied to overcome the problems of ARDS patients related to COVID-19 is HFNC.

HFNC is a respiratory support modality that supplies high oxygen levels via a nasal cannula, providing active humidification and high flow. The administration of HFNC can reduce dead space, increase carbon dioxide (CO2) removal, and provide a slight positive pressure (Parke, Eccleston and McGuinness, 2011; Frat *et al.*, 2015). HFNC is an oxygen supply system capable of delivering humidified and warmed oxygen with an oxygen fraction (FiO2) of 21% to 100% and a flow rate of up to 60 liters per minute (Sharma, S., Danckers, M., Sanghavi, D., & Chakraborty, 2021). A study reported that HFNC effectively provides respiratory support to COVID-19 patients. Research conducted on ARDS patients associated with COVID-19 comparing the use of HFNC with non-invasive ventilation (NIV) as first-line therapy showed that there was no significant difference in the duration of use of HFNC or NIV, intubation rates, and mortality between the two groups (Duan *et al.*, 2021a).

The use of HFNC has been shown to improve patient oxygenation, although results vary. One study found that 61.9% of patients experienced increased oxygenation (Hu *et al.*, 2020a). However, another study reported that 53% of patients who received HFNC therapy did not show improvement (Calligaro *et al.*, 2020a). Indecision in the use of HFNC requires intensive patient evaluation and monitoring. The effectiveness of HFNC can be seen (1) The ROX index as a comparative value between SpO2, FiO2, and respiratory rate is an indicator for assessing the success of HFNC therapy. If the ROX index value is <4.94, it indicates that the patient needs intubation (Panadero *et al.*, 2020a); (2) monitoring respiratory rate, oxygen saturation (SpO2) above 93% and clinical assessment of the patient is very important to consider success or failure (Li, Fink and Ehrmann, 2020). Therefore, the author was interested in reporting whether HFNC oxygenation therapy in ARDS patients due to complications of COVID-19 can overcome the nursing problem of impaired gas exchange.

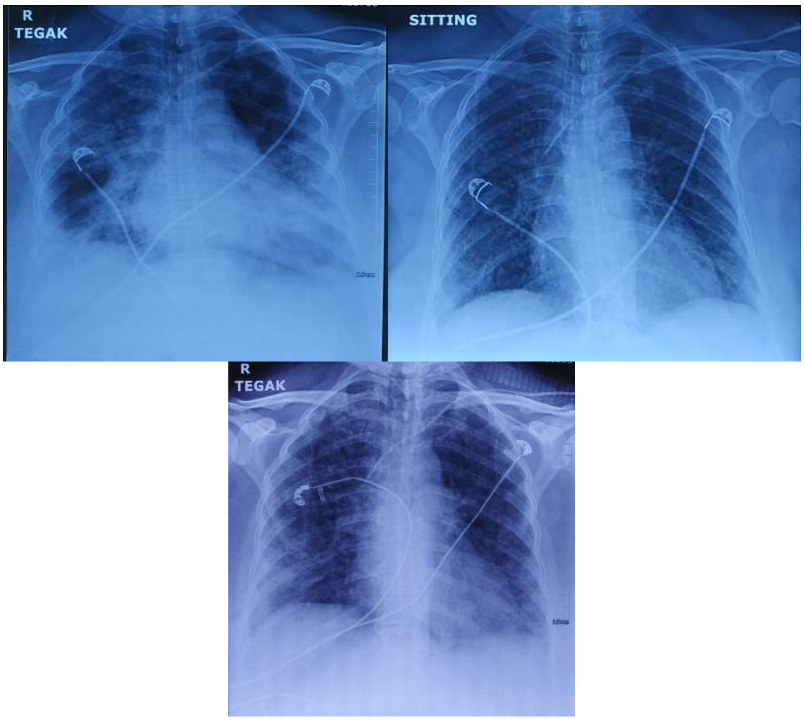
CASE REPORT

A 45-year-old female patient presented to the emergency department (ED) with symptoms including dyspnea, weakness, dry cough, fever, and diarrhea, which had persisted for two days prior to hospital admission. The patient's initial assessment revealed a moderate general condition, with the patient alert and oriented (Glasgow Coma Scale E4M6V5). Vital signs showed blood pressure of 115/53 mmHg, pulse rate of 97 beats/minute, respiratory rate of 34 breaths/minute, temperature of 37.2°C, and SpO2 of 91.6%. The preliminary diagnosis was pneumonia, suspected COVID-19.

In the ED, the patient received oxygen therapy via a non-rebreathing mask (NRM) at 15 liters per minute (lpm). The patient's medical history included vertigo and heart disease, with no known contact with COVID-19 positive individuals. The patient was also obese, with a body mass index (BMI) of 49.9. The following day, the patient's oxygenation status deteriorated (SpO2 87-89%), necessitating transfer to the intensive care unit (ICU). In the ICU, the diagnosis was confirmed as acute respiratory distress syndrome (ARDS) due to COVID-19, with a positive PCR test for SARS-CoV-2. The patient received High Flow Nasal Cannula (HFNC) oxygen therapy and had a urinary catheter and central venous catheter (CVC) inserted.

On the ninth day of ICU admission, the patient continued to experience dyspnea, weakness, decreased appetite, and sleep disturbances. Physical examination revealed a respiratory rate of 25 breaths/minute, increased tactile fremitus in lower lung fields, diminished vesicular breath sounds in upper lung fields, and bronchial breath sounds in lower lung fields, with no rhonchi or wheezing. The patient's SpO2 was 90% with HFNC (FiO2 90%, flow 60 lpm). The patient remained alert and oriented (GCS 15), with blood pressure of 122/78 mmHg, pulse rate of 107 beats/minute, and temperature of 36°C. Normal heart sounds were noted. Urine output was 3150 cc/24 hours (clear yellow), with a fluid balance of -521cc/24 hours. Bowel function was normal.

The patient required partial assistance with activities of daily living, including eating, drinking, position changes, and hygiene. The Barthel Index score was 20, indicating total dependence. Diagnostic tests included chest X-ray, blood electrolytes, complete blood count, clinical chemistry, immunology, and arterial blood gas analysis. The patient received various treatments, including HFNC oxygen therapy, convalescent plasma therapy, and medications such as anticoagulants, antivirals, anti-inflammatories, diuretics, antibiotics, zinc, vitamins C and D, and aminophylline.



1a 1b 1c

Figure 1. Thoracic X-ray examination. Impression: infiltrates both lung fields with consolidation in the lower fields of both lungs. The consolidation density in both lungs' lower fields increased more than before. Description: 1a (photo dated 3-10-2021), 1b (photo dated 3-15-2021), and 1c (photo dated 3-18-2021).

Table 1. Results of the Last Laboratory Examination

Indicator	Unit	Normal Range	Results
pH		7.37-7.44	7.44
PCO_2	mmHg	35.0-45.0	57.6
PO_2	mmHg	83.0-108.0	61.9
HCO_3	mmol/L	21.0-28.0	39
SpO_2	%	95-99	91.6
D-Dimer	ng/dL	≤500	3231
Lactic acid	mmol/L	0.5-2.2	5.0
Quantitative CRP	mg/dL	≤0.5	30.1
Procalcitonin	ng/mL	≤0.5	2.13
Absolute lymphocyte count	%	≥1500	456
Neutrophils	%	50-70	91
Lymphocytes	%	20-40	4
Hemoglobin	g/dL	11.7-15.5	10.5
Hematocrit	%	33.0-45.0	32.7
Leukocytes	ribu/uL	5.00-10.00	11.4
SGOT	U/L	≤32	92
SGPT	U/L	≤33	60
Urea	mg/dL	16.6-48.5	108.6
Creatinine	mg/dL	0.51-0.95	1.3

Based on the results of the assessment, the primary nursing diagnosis in this patient was impaired gas exchange related to changes in the alveolar-capillary membrane characterized by the patient complaining of shortness of breath, increased respiratory frequency, tachycardia, increased PCO2, decreased PO2, decreased SpO2, the impression of infiltrates and bilateral consolidation on chest x-ray. One of the collaborative interventions provided to patients to overcome major nursing problems is HFNC non-invasive oxygen therapy. The history of HFNC therapy given to the patient is explained in Table 2, and the results of monitoring the patient's clinical progress are presented in Table 3.

Table 2. History of HFNC

Treatment Day	Initial SpO2(%)	HFNC Flow Rate/ FiO2 (lpm/%)	SpO2 After HFNC (%)	Respiratory Frequency (times/minute)	Information
1	87-89	60/90	92-94	20-22	-
2	90-93	60/90	92-95	18-21	-
3	92-95	60/80	94-96	24-27	-
4	94-96	60/80	94-96	17-20	HFNC down 40/70, SpO2 89%, HFNC up to 40/80
5	95-97	40/80	96-98	18-20	-
6	96-99	40/80	96-99	18-20	HFNC decreased to 30/70, the patient was short of breath, RR 24-26 times/minute
7	95-97	50/80	88-89	25-27	HFNC rose 60/90, SpO2 96-97%, RR 21-24 times/minute
8	95-97	60/90	95-97	20-23	HFNC replaced with NRM 15 Lpm, the patient is short of breath, RR 25-29 times/minute, SpO2 88-89%
9	90-92	60/90	90-93	20-22	-

Table 3. Results of Monitoring Patient Progress

Treatment day	SpO_2 (%)	Respiratory Frequency (times/minute)	ROX Index (SpO2/FiO2/RR)	SOFA Score
1	92-94	20-22	5.22	-
2	92-95	18-21	5.86	4
3	94-96	24-27	5.00	-
4	94-96	17-20	7.06	3
5	96-98	18-20	6.80	-
6	96-99	18-20	6.87	-
7	96-97	25-27	4.98	4

8	95-97	20-23	5.39	-
9	90-93	20-22	5.11	-

Discussion

The severity of patients infected with COVID-19 is due to the presence of comorbidities. Obesity is one of the most common comorbidities of COVID 19 with signs and symptoms such as shortness of breath, dry cough, fever, diarrhea, weakness, hypoxemia, damage to kidney function (marked by increased urea and creatinine), and usually experiencing shortness of breath and dyspnea within 7 to 10 days after symptom onset and some will develop ARDS (Wang *et al.*, 2021). ARDS causes patients to experience respiratory failure, heart failure, and excess fluid volume. The damage can be seen from chest x-ray examination showing bilateral consolidation in the lung basalts and lung examination with a calculated PaO2/FiO2 ratio of 68.78 (<300 mmHg) (Esakandari *et al.*, 2020). Based on the assessment, the patient's main nursing problem is impaired gas exchange. This gas exchange disorder is associated with changes in the patient's pulmonary alveolar-capillary membrane. Normal lungs have structures to facilitate carbon dioxide excretion and oxygen transfer across the distal alveolar-capillary units (Bhattacharya and Matthay, 2013). In ARDS patients, there is damage to the lung epithelial and endothelial cells. This damage is characterized by inflammation, apoptosis, necrosis, and increased alveolar-capillary permeability, leading to the development of alveolar edema as well as proteins. Alveolar edema ultimately reduces gas exchange and causes hypoxemia (Huang *et al.*, 2018b).

One of the collaborative interventions given to overcome the problem of gas exchange disorders is non-invasive HFNC oxygen therapy. HFNC has been shown to be a useful therapy in ARDS and is better tolerated by patients than other non-invasive ventilation methods. Meanwhile, HFNC, compared to mechanical ventilation methods, has less risk of causing ventilator-induced lung injury (Rochwerg *et al.*, 2019a), as well as avoiding intubation-related nosocomial complications (Panadero *et al.*, 2020b). HFNC has been used to reduce the need for intubation in ARDS patients (Azoulay *et al.*, 2017; Rochwerg *et al.*, 2019b; Mellado-Artigas, Ferreyro, *et al.*, 2021a). Currently, HFNC therapy is also used in COVID-19 patients with acute respiratory failure. The use of HFNC in COVID-19 patients with ARDS was first carried out due to the increasing need for hospitalization and limited ventilator equipment (Delbove *et al.*, 2021). Based on the guidelines for handling COVID-19 issued by WHO, adult patients with ARDS can be given HFNC therapy up to 60 Lpm and FiO2 100% (WHO, 2021a, 2023a).

The patient's history of HFNC therapy is presented in Table 2. The patient received HFNC therapy from the first day of being treated in the ICU. This is in accordance with WHO guidelines, where HFNC therapy must be given in a setting where it can be monitored. Patients should also receive supervision from experienced health workers who are able to perform endotracheal intubation if the patient's condition suddenly worsens or there is no change after one hour of therapy (WHO, 2021b, 2023b). The ROX index value (SpO2/FiO2/breathing frequency) has a good predictive capacity in assessing the success of HFNC therapy. A ROX index value <4.94 indicates that the patient requires immediate intubation (Panadero *et al.*, 2020b). The ROX index value in this patient during the 9 days treated with HFNC ranged from 4.98 to 7.06. This means that the patient does not require intubation and can continue HFNC therapy

When treated with HFNC therapy, patients showed improved oxygenation status (SpO2). This aligns with research findings showing that the majority of COVID-19 patients (61.9%) experienced improved oxygenation status (Hu *et al.*, 2020b). The increased oxygenation occurs through several mechanisms. HFNC is a device that delivers oxygen at high flow rates and concentrations.

The high oxygen flow provides a larger volume of air compared to the patient's physiological ventilation, thereby improving ventilation and allowing the exchange of excess CO_2 (in the dead space) with excess O_2 (delivered through the HFNC). This increases PaO_2, creating a greater oxygen diffusion gradient and improving patient oxygenation. Therefore, HFNC also enhances oxygenation by reducing nasopharyngeal resistance through the application of positive pressure (Nishimura, 2015). Additionally, HFNC use can decrease respiratory rate and increase tidal volume. Furthermore, HFNC creates positive end-expiratory pressure in the lower respiratory tract, preventing alveolar collapse. This positive end-expiratory pressure also increases alveolar recoil and expands the effective lung surface area for gas diffusion to and from the bloodstream (Parke and McGuinness, 2013; Parke, Bloch and McGuinness, 2015).

Several studies have evaluated additional benefits of HFNC therapy beyond improved oxygenation in COVID-19 patients with ARDS. Sayan et al. in their research concluded that HFNC can reduce intubation requirements and mortality rates in patients with COVID-19-related acute respiratory failure (Sayan *et al.*, 2021). This was corroborated by Patel et al., who found that HFNC use is associated with reduced rates of invasive mechanical ventilation and mortality in COVID-19 patients (Patel *et al.*, 2020). However, it should be noted that HFNC has the potential to increase viral spread through aerosols (Elshof *et al.*, 2020; Jermy *et al.*, 2021). Therefore, patient rooms must have adequate ventilation systems, and all healthcare staff caring for patients must use appropriate personal protective equipment (WHO, 2021b, 2023b).

From day one to nine of treatment, the patient received HFNC therapy with FiO_2 ranging from 70% to 90% and flow rates of 30-60 Lpm (see Table 2). The FiO_2 and oxygen flow rates were adjusted based on the patient's oxygenation status, including SpO_2, respiratory rate, and reported dyspnea. In this case, comprehensive monitoring and evaluation were essential for the patient receiving HFNC therapy. Monitoring the Sequential Organ Failure Assessment (SOFA) score, ROX index, and oxygenation status—including respiratory rate, SpO_2, and clinical assessment—was crucial in evaluating HFNC therapy success or failure. This is explained by the fact that not all patients receiving HFNC show improved oxygenation status. Several studies reported that 54% (Mellado-Artigas, Mujica, *et al.*, 2021), 53% (Calligaro *et al.*, 2020b), and 38.1% (Hu *et al.*, 2020b) of patients showed no improvement and required mechanical ventilation. Higher SOFA scores (typically >7) and lower ROX indices (<4.94) are associated with mechanical ventilation requirements (Mellado-Artigas, Ferreyro, *et al.*, 2021b). One study indicated that if patients show declining oxygenation status, non-invasive or mechanical ventilation should be considered immediately (Duan *et al.*, 2021b). However, in our case, while the monitoring parameters fluctuated (SOFA score, ROX index, SpO_2, and respiratory rate; see Table 3), they remained within acceptable ranges (SOFA score <7, ROX index >4.94, average SpO_2 ≥93%, and respiratory rate <30 breaths/minute). Therefore, in this situation, HFNC therapy could be continued until oxygenation status improved or mechanical ventilation became indicated.

Conclusion: SARS-CoV-2 viral infection presents with a range of symptoms, from mild to severe, and can progress to ARDS. One of the nursing diagnoses in COVID-19 ARDS patients is impaired gas exchange due to alveolar-capillary membrane damage. A collaborative intervention that can be administered is oxygen therapy via HFNC. HFNC therapy can improve oxygenation status and delay or prevent intubation in COVID-19-associated ARDS patients. The use of HFNC must comply with appropriate guidelines to optimize patient outcomes and prevent the risk of viral spread through aerosols. Nurses play an important role in monitoring SOFA scores, ROX index, SpO_2, respiratory rate, and clinical conditions to assess HFNC therapy success or failure. Additionally, to improve patient oxygenation, HFNC therapy may be combined with other evidence-based interventions, such as prone positioning.

Declaration: The patient's identity has been fully anonymized to maintain privacy and confidentiality. Informed consent was obtained from the patient for publication of this case report without including any identifiable information.

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