ORIGINAL ARTICLE

Gastric Insufflation with High Flow Nasal Oxygen Therapy in Adult Patients Admitted to Intensive Care Unit: An Observational Study

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Abstract

Background: With the provision of a small positive end-expiratory pressure (PEEP) effect, high-flow nasal oxygen (HFNO) therapy carries a risk of stomach distension. The present study was conducted to find out the air leak in the gastric antrum leading to gastric distension in adult patients with acute respiratory failure receiving HFNO therapy.

Materials and methods: Adult patients with early hypoxemic respiratory failure requiring HFNO therapy were enrolled in this trial. Before initiation of HFNO therapy, baseline gastric volume (GV) and the average number of peristaltic contractions over one minute were measured using ultrasound. Once the patient was stabilized on HFNO therapy, a 2nd, 3rd, and 4th ultrasound scans were acquired at 10, 20, and 30 minutes respectively. Vitals and blood gas values were recorded at the baseline and after 30 min of initiation of HFNO therapy. Patient comfort, duration of HFNO therapy, and outcome were also recorded.

Results: The GV at 10, 20, and 30 minutes were significantly larger ($p < 0.001$) compared to baseline. This increase in GV was associated with a significantly increased number of peristaltic contractions and had a significant positive correlation with the HFNO flow ($r = 0.541$; $p < 0.001$). The HFNO therapy was well tolerated by most of the patients and led to a significant improvement in the vitals and blood gas parameters at 30 minutes after initiation of HFNO therapy.

Conclusion: In adult patients with hypoxemic respiratory failure, the use of HFNO therapy produces gas leaks into the stomach leading to increased gastric volume. The gastric distension increases the peristaltic contraction and higher flows result in more distension.

Keywords: Air, Critically ill, Oxygen therapy, Stomach, Ultrasound.

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Highlights

- A small positive end-expiratory pressure (PEEP) effect associated with high-flow nasal oxygen (HFNO) carries a risk of gastric distention and critically ill patients with respiratory failure are at increased risk.
- We aim to find out the air leak into the gastric antrum with a consequent increase in gastric volume (GV) during HFNO therapy.
- We found that HFNO produces air leaks leading to increased GV and peristaltic contraction with higher flows causing more distension.

Introduction

In critical care settings, oxygen is commonly used to achieve a normal or near-normal peripheral oxygen saturation (SpO_2) in acute and chronically hypoxic patients. Physicians often aim for a SpO_2 of 94–95%, or a patient-specific target of 88–92% for those at risk of hypercapnic respiratory failure.[1] Conventional oxygen therapy (COT) delivery systems neither warm nor humidify the inspired gas nor deliver a reliable fraction of inspired oxygen (FiO_2) leading to poor tolerance when used for prolonged periods. High flow nasal oxygen is an increasingly used therapy that allows high flows and FiO_2 at a more physiological level of temperature and humidity. Given the evident benefits, HFNO therapy has emerged as a valuable substitute for COT and other non-invasive respiratory support systems in patients suffering from acute and chronic respiratory failure.[2,3]

Research on non-invasive ventilation (NIV) has revealed that the respiratory system resistance and lower esophageal sphincter pressure cause the ventilation volume to be distributed between the stomach and lungs, resulting in gastric distension.[4] As the HFNO creates small PEEP, it also carries a theoretical risk of gastric distension. According to research done on healthy individuals, the use of HFNO is not linked to an increase in stomach volume

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(GV) during spontaneous breathing.[5] However, these results can't be extrapolated to critically ill patients since they have altered respiratory system mechanics. A case report highlighted the critical abdominal distension with abdominal compartment syndrome after the application of HFNO in a 21-month-old baby with a history of chronic lung disease.[6] Due to the paucity of literature, studies are required to find out the possibility of air leaks into the gastric antrum leading to distension in critically ill patients requiring HFNO therapy.

The present study hypothesized that HFNO therapy in adult critically ill patients could produce air leaks into the gastric antrum leading to increased GV and gastric distension. The primary objective of the study was to compare the GV at the baseline with the GV at predefined time intervals (10, 20, and 30 minutes) after initiation of HFNO therapy. The secondary objectives were to find out the incidence of air leaks and a number of patients developing 'at-risk' stomach (GV > 0.8 mL.kg^{-1} or > 1.5 mL.kg^{-1}); to compare the number of peristaltic contractions of gastric antrum at the baseline with the peristaltic contractions at 10 minutes; and to assess the correlation between the flow rates and gastric distension, improvement in blood gas parameters, patient comfort, duration of HFNO therapy and outcome.

Materials and Methods

This prospective, single-arm observational study was carried out in an adult intensive care unit under the Department of Anaesthesiology and Critical Care. After obtaining approval from the institutional ethical committee (Certificate Reference Number-AIIMS/IEC/2019-20/995 dated 18/11/2020), the study was registered prospectively with the clinical trial registry India (CTRI) (Registration No.: CTRI/2021/03/031608 dated 01/03/2021; Principal Investigator: Dr. Pradeep Bhatia; Period of recruitment April 2021 to Dec 2022). Every step of the process was carried out in compliance with the 1975 Helsinki Declaration and the ethical guidelines established by the Local Institutional Committee on Human Experimentation.

Patients aged more than 18 years, admitted to the ICU, and in whom the need for HFNO therapy was recognized by the treating intensivist were enrolled after obtaining written and informed consent. The study excluded patients with psychiatric, agitated, or non-cooperative conditions; pregnant women; patients in severe respiratory failure requiring immediate tracheal intubation and mechanical ventilation; obese patients; patients with cardiovascular, renal, or hepatic illness; postoperative patients following upper abdominal surgery or surgery on the face, nose, or airway; patients on continuous nasogastric tube aspiration; and patients with abnormalities of the face.

After giving a detailed description of the study and obtaining informed consent, a brief history of each patient was obtained including comorbidities, duration of respiratory illness, and medications. Once the decision on initiation of HFNO therapy was made by the treating intensivist, the baseline vitals [heart rate (HR), respiratory rate (RR), blood pressure, and SpO_2], arterial blood gas (ABG) parameters [partial pressure of oxygen (PaO_2) and carbon-dioxide ($PaCO_2$), PF ratio (PaO_2/FiO_2), and arterial oxygen saturation (SaO_2)] and ultrasound guided estimation of GV and the number of antral peristaltic contractions were recorded. Following this, HFNO (Airvo2, Fisher and Paykel Healthcare) therapy was initiated using a nasal cannula (Optiflow, Fisher and Paykel Healthcare) as per institutional protocol, and the required HFNO flow and FiO_2 were recorded. At our institute, the HFNO is initiated at a flow rate of 60 L/min and FiO_2 of 1.0 with subsequent adjustment as per the patient's need to keep the RR ≤ 30 and SpO_2 ≥ 94%.

The stomach antrum was assessed qualitatively and quantitatively using a portable ultrasound machine (Venue GoTM, GE Healthcare, Chicago, United States) equipped with a curvilinear low-frequency (3–5 MHz) transducer. Over the course of the study, two authors (SM and MK) with over 5 years of point-of-care ultrasound experience conducted the ultrasound examinations.

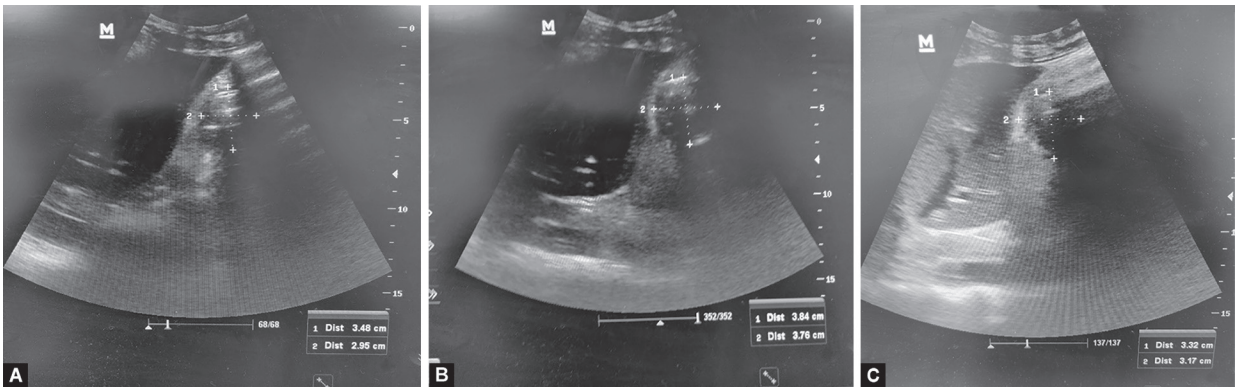
To ensure consistent measurements, the average of three consecutive ultrasound scans was recorded for analysis at each time of observation. Additionally, all the scans were reviewed by another author (PB). The study rejected the patient's data if the primary measurement and the reviewed measurement differed by more than 0.5 cm in the anteroposterior and transverse dimensions. Patients were positioned in the right lateral position with their heads 45 degrees elevated for the ultrasonography assessment. The gastric antrum was imaged in the sagittal plane in the epigastrium, along the edge of the left lobe of the liver, and at the level of the aorta.

The maximal anteroposterior diameter (D1) and transverse diameter (D2) of a single section of the gastric antrum between the peristaltic contraction was determined and antral cross-sectional area (ACSA) was calculated using the formula (ACSA = (π × D1 × D2) ÷ 4). From ACSA, the GV was calculated using a mathematical model [GV (mL) = –215 + 57 log ACSA (mm^2)–0.78 age (year)–0.16 height (cm)–0.25] reported by Bouvet and colleagues based on gastroscopic fluid assessment with a reference standard of nasogastric suction.[7]

Further gastric ultrasound measurements were done at 10, 20, and 30 minutes after the stabilization of the patient to detect any air leaks into the stomach and changes in the GV (Fig. 1). The air leak in the gastric antrum, defined by qualitative ultrasound as a distended antrum with air content that blurs the posterior antral wall was recorded. At 10 minutes, the average number of peristaltic contractions of the stomach in one minute was calculated after counting the peristaltic contractions of the stomach for a period of 5 minutes. Vitals and ABG values were recorded 30 minutes after the start of HFNO therapy. The comfort of the patients on HFNO therapy was recorded at the end of the study on a scale of good, fair, or poor based on their subjective feelings and opinions. Patients' complaints of gastric distension, bloating, burping, and excessive flatulence were also recorded. Both the outcome of the HFNO therapy and its overall duration were documented.

Statistical Analysis

Sample size calculation was based on the primary outcome measure of our study i.e., an increase in GV. The GV considered as an 'at-risk' stomach has been defined as 0.8 mL.kg^{-1}.[8] We assumed that 40% of patients receiving HFNO therapy would develop an 'at-risk' stomach. A total of 76 subjects were required for a significance of 5% and a power of 80% to detect this difference. The data collected was entered in Microsoft Excel. The Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, version 23.0 for Windows) was used for all statistical analyses. Nominal variables were described using counts or percentages and were analyzed using the Chi-square test. The median and quartiles were used to describe ordinal variables and continuous variables with non-normal distribution. The Mann-Whitney *U* test was used to evaluate unpaired data, and the Wilcoxon Rank Sum test was used to examine paired data. The Kruskal-Wallis test was used to compare paired repeated measures. Spearman's correlation was calculated to find an association



Figs 1A to C: The 2D image of the gastric ultrasound at 10, 20, and 30 minutes respectively after initiation of the HFNO therapy showing anteroposterior (D1) and transverse diameter (D2) of the gastric antrum

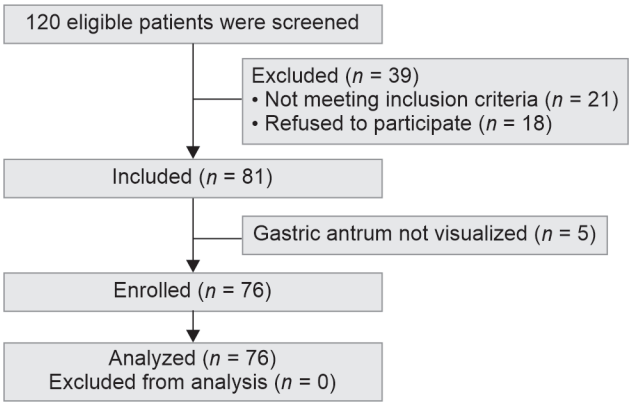


Fig. 2: Patients' flow during the study period

Table 1: Demographic profile, duration of illness and time to last meal of the study population

S. No.	*Variable*	*Median (quartiles) or number*
1	Age (years)	61.50 (46.5, 68.0)
2	Gender (male/female)	52/24[†]
3	Height (cm)	165 (159, 168)
4	Weight (kg)	68.5 (59, 74)
5	BMI (kg/m^2)	25.1 (22.9, 27.2)
6	Duration of illness (days)	14 (7.25, 20)
7	Time of last meal (min)	
	Liquid	90 (45, 120)
	Solid	360 (200, 480)

BMI, body mass index; [†]data presented as number

between HFNO flow rate and gastric distension. The *p*-value < 0.05 was considered significant.

Results

During the study period, 120 patients were screened for eligibility, and out of them, 39 were excluded (21 not meet inclusion criteria and 18 refused to participate). Of the 81 patients included, gastric antrum was not visualized in 5 (6.2%) patients, and data from the remaining 76 patients were analyzed (Fig. 2). The demographic profile (age, gender, height, weight, body mass index), duration of illness, and time to last meal of the study population are presented in Table 1. The D1 at 20 and 30 minutes was significantly larger (*p*-value 0.045 and 0.003, respectively) compared to the baseline, however, the repeated measures test showed a non-significant increase in D1 (Table 2). The D2, ACSA, and GV at 10, 20, and 30 minutes were significantly larger ($p < 0.001$) compared to the baseline, and the repeated measures test also showed a significant increase in D2 (Table 2). The number of patients with 'at-risk' stomach (GV > 0.8 mL.kg^{-1}) increased from 16 (21.1%) at baseline to 45 (59.2%) at 30 minutes while they were 4 (5.26%) and 17 (22.3%) respectively for GV > 1.5 mL.kg^{-1}.

There was a significant increase in the number of peristaltic contractions at 10 minutes after initiation of the HFNO therapy compared to baseline [median difference (95% confidence interval) 1 (0.8–1.4)] (*p*-value < 0.001) (Fig. 3). Significantly higher numbers of patients had air leaks at 10, 20, and 30 minutes ($p = 0.001$) compared with air leaks at 0 minutes. The incidence of air leaks at 10, 20, and 30 minutes were found to be 17.1, 53.9, and 60.5%, respectively. In the study population, 46 (60.5%) patients demonstrated an increase in GV after initiation of the HFNO therapy, and a higher flow rate was associated with a higher number of patients with increased GV. There was a significant positive correlation ($r = 0.541$) ($p = < 0.001$) between HFNO flow and the number of patients with an increase in GV (Fig. 4).

We documented a significant increase in SpO_2, PaO_2, PF ratio, and SaO_2 with a significant fall in RR and $PaCO_2$ 30 minutes after the initiation of HFNO therapy compared to the baseline ($p < 0.001$) (Table 3). None of the patients complained of gastric distension, bloating, burping, and excessive flatulence however nausea/vomiting was observed in 7 patients (9.2%) after 30 minutes of HFNO therapy. Patient's comfort level ranged between good to fair in the majority of cases whereas it was poor in 9.2% of cases. The median (IQR) total duration on HFNC was 4 (2.25, 8). A total of 41 patients (53.9%) experienced worsening in the condition out of which 34 patients (44.7%) were subsequently treated with invasive or noninvasive ventilation and 7 patients (9.2%) succumbed to death.

Discussion

In critically ill adult patients, the use of the HFNO therapy produces air leak into the gastric antrum leading to increased GV. However, none of the patients complained of symptoms related to gastric distension. After initiation of the HFNO therapy, there was a significant increase in both the anteroposterior and transverse diameter thereby increasing calculated ACSA and GV. This increase in GV was associated with a significantly increased number of peristaltic contractions and had a significant positive correlation

Table 2: Comparison of gastric antral diameters, area and volume before and after initiation of HFNO therapy

Parameter	*Time (min)*	*Median (quartiles)*	*Median diff (95% CI) compared to baseline*	*p-value (compared to baseline)*	*p-value (repeated measure)*
D1 (cm)	0 min	2.3 (1.6, 2.9)	–	–	0.22
	10 min	2.4 (1.9, 2.8)	0.1 (–0.2–0.0)	0.67	
	20 min	2.5 (2.1, 3.0)	0.2 (0.0–0.3)	**0.045**	
	30 min	2.6 (1.9, 3.1)	0.3 (0.1–0.4)	**0.003**	
D2 (cm)	0 min	2.2 (2.0, 2.4)	–	–	**<0.001**
	10 min	2.6 (2.3, 3.0)	0.36 (0.4–0.7)	**<0.001**	
	20 min	2.7 (2.4, 3.2)	0.46 (0.4–0.7)	**<0.001**	
	30 min	2.6 (2.2, 3.1)	0.4 (0.3–0.6)	**<0.001**	
ACSA (cm^2)	0 min	400.2 (279.6, 463.0)	–	–	**<0.001**
	10 min	483.4 (380.7, 695.7)	83.21 (77.3–158.2)	**<0.001**	
	20 min	501.5 (392.5, 663.8)	101.27 (95.5–172.6)	**<0.001**	
	30 min	483.6 (332.6,776.5)	83.38 (104.5–212.5)	**<0.001**	
GV (mL)	0 min	51.9 (37.9, 68.9)	–	–	**<0.001**
	10 min	64.9 (45.4, 88.3)	13.0 (9.6–17.7)	**<0.001**	
	20 min	69.2 (50.1, 86.6)	17.3 (11.9–21)	**<0.001**	
	30 min	63.0 (42.0, 93.9)	11.1 (10.7–23)	**<0.001**	

ACSA, antral cross-sectional area; D1, anteroposterior antral diameter; D2, transverse antral diameter; GV, gastric volume. Wilcoxon signed rank test was used to comparison with baseline while Friedman test was used for repeated measures

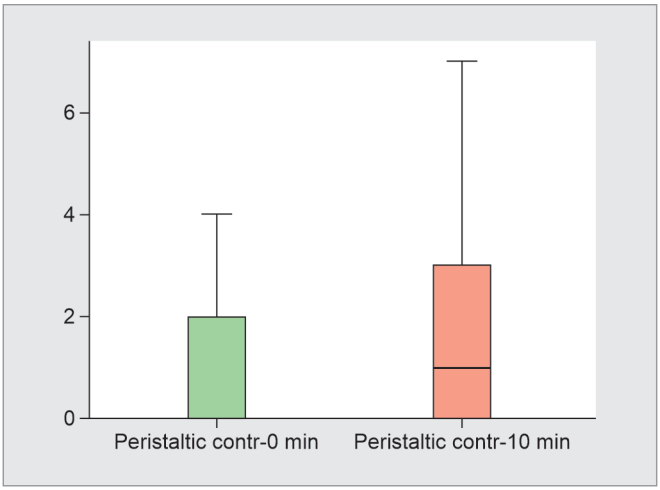


Fig. 3: Comparison of the number of gastric peristaltic contractions at baseline and at 10 minutes after initiation of HFNO therapy

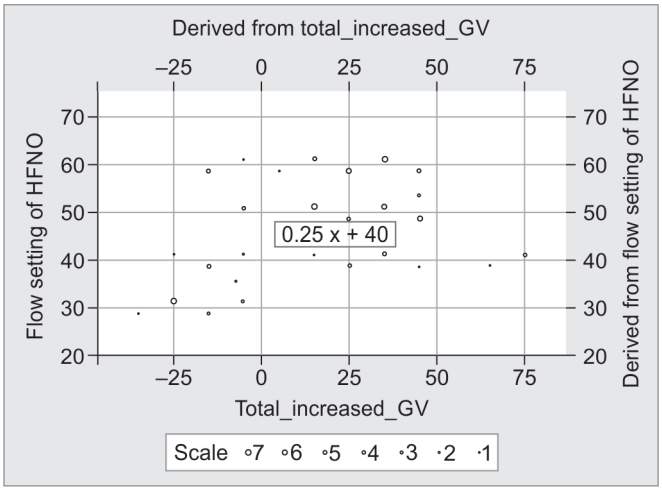


Fig. 4: Scatter plot demonstrating the correlation between HFNO flow and a total increase in gastric volume

with the flow delivered during the HFNO therapy. The HFNO therapy was associated with a significant increase in the SpO_2, PaO_2, PF-ratio, and SaO_2 and a significant decrease in the RR and $PaCO_2$.

The HFNO therapy is an innovative technique that can meet or exceed the patient's spontaneous inspiratory flow by providing heated and humidified gases at a high flow rate and has been postulated to exert beneficial effects like pharyngeal dead-space washout, decrease in airway resistance, and provision of PEEP.[9] It is now used as a substitute for NIV in critically ill patients with acute hypoxemic respiratory failure in order to provide initial respiratory support while maintaining appropriate oxygenation and partially assisting with alveolar ventilation. The effectiveness of HFNO therapy in reducing respiratory frequency, work of breathing, and the requirement for respiratory support escalation has been demonstrated in a number of studies.[9]

Respiratory therapy using NIV has been shown to be effective, however, delivery of gases at higher pressure often leads to aerophagia with consequent gastric distension.[10] The distension caused by aerophagia leads to increased parasympathetic tone and induces airway inflammation exacerbating bradycardia and bronchoconstriction respectively.[4,11,12] The PEEP effect associated with HFNO therapy has been reported as a cause of tension pneumocephalus.[13] Therefore, it also carries a theoretical possibility of aerophagia and consequent gastric distension and the same has been reported in the literature.[6,14] A new non-invasive, quick, easy, and diagnostic test for the bedside that assesses the contents of the stomach both qualitatively and quantitatively is gastric ultrasonography.[15] It has been used extensively in critically ill patients to guide enteral feeding.[16]

We found a significant increase in GV from the baseline at 10, 20, and 30 minutes after initiation of HFNO therapy. Testa G et al. compared the HFNO therapy and COT in pediatric cardiac surgical patients and found 2 cases of abdominal distension requiring suspension of HFNO therapy.[14] Satoki Inoue et al. reported critical

Table 3: Comparison of vitals and blood gas parameters before (at 0 min) and after (at 30 min) initiation of HFNC therapy

Parameter	*Baseline (at 0 min) [median (quartiles)]*	*At 30 min [median (quartiles)]*	*Median diff (95% CI)*	*p-value*
HR (per min)	98.5 (79.8, 118)	99.0 (76.3, 114)	0.5 (–0.6–3.9)	0.08
MAP (mm Hg)	95.3 (82.2, 102.6)	93.3 (85.3, 103.1)	2 (–2.5–1.3)	0.97
SpO_2 (%)	88 (86, 89)	93.5 (91, 94)	5.5 (5.0–5.9)	**<0.001**
RR (per min)	30 (26, 35)	26 (22, 32)	4 (2.4–3.5)	**<0.001**
PaO_2 (mm Hg)	71.7 (65.2, 78)	78.6 (70.3–87.5)	6.9 (6.7–12.6)	**<0.001**
$PaCO_2$ (mm Hg)	41.6 (39, 45)	40 (37.9, 44.1)	1.6 (0.6–1.5)	**<0.001**
PF ratio	108.3 (93, 134.5)	120.4 (100.0, 158.9)	12.1 (11–23.9)	**<0.001**
SaO_2 (%)	88 (85.6, 88)	91 (89.6, 92)	3 (3.1–4)	**<0.001**

DBP, diastolic blood pressure; HR, heart rate; MAP, mean arterial pressure; SBP, systolic blood pressure; SpO_2, peripheral oxygen saturation; PF ratio, ratio of partial pressure of arterial oxygen and fraction of inspired oxygen; PaO_2, partial pressure of arterial oxygen; $PaCO_2$, partial pressure of arterial carbon dioxide; RR, respiratory rate; SaO_2, saturation of arterial oxygen Wilcoxon signed rank test was used for comparison with baseline

abdominal distension in a 21-month-old boy with a history of chronic lung disease.[6] The patients in both the published reports are expected to have reduced lung compliance predisposing them to gastric distension. In contrast, Elizabeth McLellan et al. found that there was no evidence of gastric distension or an increase in gastric secretions with HFNO at a flow rate of up to 70 L/min for 30 minutes in healthy fasted adult volunteers.[5] Sud et al. compared the gastric gas volumes measured by computed tomography after HFNO therapy and conventional facemask ventilation in the perioperative context and found no significant difference in the gastric volume between groups.[17] However, since the study population in both studies was expected to have normal lung compliance, the results obtained cannot be extrapolated to critically ill patients.

When 'at-risk' stomach was defined as GV > 0.8 $mL.kg^{-1}$, the percentage of patients increased from 21% at 0 minutes to 59% at 30 minutes while it was 5 and 22% respectively when 'at-risk' stomach was defined as GV > 1.5 $mL.kg^{-1}$. Since a higher volume of gas is required to exert the equivalent pressure and produce the same degree of gastric distension as a liquid would, a GV > 1.5 $mL.kg^{-1}$ might be a more conservative estimate for GV for defining the at-risk stomach.

Increasingly more numbers of patients had air leaks at 10, 20, and 30 minutes after initiation of HFNO therapy. The presence of air in the stomach obscuring the posterior wall made it difficult to reliably ascertain the ACSA and thereby the GV. In the present study, we followed the contour of both lateral walls to assume the posterior antral wall in the presence of air. Although the air leak in the stomach leads to a significant increase in peristaltic contractions suggestive of gastric distension, none of the patients complained of symptoms related to gastric distension indicating its benign nature.

The increase in the GV had a significant positive correlation with the HFNO flow. Higher flow creates higher nasopharyngeal pressure and consequent higher air leak into the stomach and gastric distension. Parke et al. measured nasopharyngeal pressure with nasal flow oxygen at flows of 30, 40, and 50 L/min with patients' mouths both open and closed. They concluded that mean nasopharyngeal pressure during nasal high-flow oxygen increases as the flow increases.[18]

The respiratory parameters were significantly improved after the initiation of HFNO therapy. Sztrymf et al. found that HFNO significantly reduced RR, HR, dyspneic score, supraclavicular retraction, and thoracoabdominal asynchrony and increased pulse oximetry as early as 15 minutes after the beginning of the HFNO therapy. The PaO_2 and PaO_2/FiO_2 increased significantly after 1 hour of HFNO in comparison with the baseline.[19]

There are a few limitations of our study, which should be kept in mind while interpreting the results. First, the presence of air in the stomach obscuring the posterior antral wall might have led to over or under-estimation of measured GV though we carefully followed the contour of both lateral walls for assuming the posterior wall. Second, gastric ultrasound has a few limitations, particularly in the presence of air in the stomach therefore, the use of computed tomography for GV measurement might produce different results. Third, as gastric dilatation is a known complication of critical illness, stratifying the study population based on the level of illness might demonstrate differences in the population. However, our study aimed to assess the HFNO-induced 'air leak' in the stomach leading to gastric distention. Further studies are warranted with a larger sample size to reciprocate the findings of our study.

Conclusion

In adult patients with early hypoxemic respiratory failure, the use of HFNO therapy produced air leaks into the stomach leading to increased gastric volume and gastric distension. This increases the peristaltic contractions of the stomach without developing the symptoms of gastric distension and higher flows results in more distension. The HFNO therapy was well tolerated and significantly improved the respiratory parameters.

Trial Registration

This trial was prospectively registered at the clinical trial registry, India (https://ctri.nic.in/) (CTRI/2021/03/031608 dated 01/03/2021, Period of recruitment April 2021 to Dec 2022).

IEC Approval Certificate Reference

Certificate reference number: AIIMS/IEC/2019-20/995 dated 18/11/2020; Study title: Gastric insufflation with high flow nasal oxygen therapy in patients admitted in adult intensive care unit: An observational study.

Presentation

Critical Care Congress, SCCM 2023, January 21–24, 2023 at the Moscone Center South San Francisco, California.

Author Contribution's

AR: Helped in conception and design of the study, acquisition, analysis and interpretation of data, literature search, drafting, critical revision and final approval of the work; PB: Helped in conception and design of the study, acquisition, analysis and interpretation of

data, literature search, drafting, critical revision and final approval of the work; SM: Helped in conception and design of the study, acquisition, analysis and interpretation of data, literature search, drafting, critical revision and final approval of the work; MK: Helped in the conception and design of the study; drafting, critical revision and final approval of the work. SC: Helped in the conception and design of the study, drafting, critical revision and final approval of the work; BP: Helped in the conception and design of the study, drafting, critical revision and final approval of the work.

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