Capnographic Analysis of Minimum Mandatory Flow Rate for Hudson Face Mask: A Randomized Double-blind Study

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Abstract

Background: Oxygen supplementation through Hudson type face mask is frequently used in perioperative settings. Hudson mask is a variable rate performance device with the risk of rebreathing. Studies using capnography to find out an actual fraction of rebreathing in spontaneously breathing patients are not available. Aims: In this study, we analyzed the effects of different flow rates through Hudson mask with capnography on fractional inspired carbon dioxide (FiCO$_2$). Setting and Designs: Forty patients posted for minor surgeries under monitored anesthesia care were divided into four groups. They received oxygen flow rate of 3 L/min, 4 L/min, 5 L/min, and 6 L/min as per group division, through Hudson mask. Materials and Methods: Parameters such as pulse rate, noninvasive blood pressure, oxygen saturation, respiratory rate (RR), end-tidal carbon dioxide (EtCO$_2$), and FiCO$_2$ were noted at baseline. After starting oxygen supplementation, these parameters were monitored every minute for ten minutes. Statistical analysis was done using analysis of variance and Kruskal–Wallis test. Pearson correlation was used to establish a relation between RR and FiCO$_2$. Results and Conclusions: EtCO$_2$ and FiCO$_2$ were comparable in all four groups with no statistical significance. There was strong positive correlation seen between RR and FiCO$_2$ at a flow rate of 3 L/min while negative correlation in other groups. We conclude that FiCO$_2$ is similar at all flow rates while breathing through Hudson mask. Increase in RR can cause increase in FiCO$_2$ at lower flow rate, which is within physiological tolerance limits.

Keywords: Capnography, carbon dioxide, minor surgical procedures, monitoring, oxygen mask

INTRODUCTION

Oxygen is the most widely used drug perioperatively and during critical care. Oxygen supplementation through Hudson face mask (simple face mask) is frequently used in perioperative settings. This method of oxygen delivery is cheap, easy to administer and acceptable to both patients and anesthesiologists in routine cases. Hudson mask is a variable rate performance device which depends on the oxygen flow rate, reservoir effect size of the mask, peak inspiratory flow rate (PIFR), and respiratory rate (RR). The fraction of inspired oxygen concentration (FiO$_2$) varies depending on these factors, and there is always risk of carbon dioxide (CO$_2$) rebreathing. Although there are different types of oxygen delivery devices available which perform predictably better, Hudson type mask is used most commonly. The literature about the performance of Hudson type masks mentions about flow rates, FiO$_2$ and arterial partial pressure of CO$_2$ (PaCO$_2$). The data regarding the relationship between CO$_2$ rebreathing and oxygen flow rate through Hudson mask is limited. The recommended flow rate for Hudson face mask to avoid rebreathing is 4-10 L/min. However, in clinical practice use of 3 L/min of flow rate is frequently seen. The increase in flow rate does not improve oxygenation and performance can deteriorate with an increase in minute ventilation. Hence, the flow rate at which no CO$_2$ rebreathing is seen appears to be minimum mandatory flow for Hudson mask. The previous study done on healthy human volunteers with the help of plethysmography recommends minimum flow of 5 L/min to avoid rebreathing. CO$_2$ rebreathing can lead to increase in work of breathing which cannot be detected by clinical signs or pulse oximetry.

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based on plethysmography or oximetry and the amount of rebreathing is calculated based on various factors. To the best of our knowledge, studies using capnography to find out an actual fraction of inspired CO\(_2\) (FiCO\(_2\)) in spontaneously breathing patients are not available. In this study, we compared the effect of different flow rates through Hudson mask on CO\(_2\) rebreathing (FiCO\(_2\)) with capnography.

The primary aim of our study was to find out the minimum flow rate at which no CO\(_2\) rebreathing is seen at any time during the study. The secondary aim of the study was to compare hemodynamic parameters, RR, end-tidal CO\(_2\) (EtCO\(_2\)), oxygen saturation (SpO\(_2\)), and integrated pulmonary index (IPI) between groups.

**Materials and Methods**

This was a prospective randomized double-blind study conducted over a period of 3 months from August 2016 to October 2016, after obtaining approval from the Institutional Ethics Committee (IEC No. 2016/261). The trial was registered in clinical trial registry – India, before starting enrollment of patients (CTRI/2017/02/007807). Patients between 18 and 40 years of age of physical status American Society of Anesthesiologist (ASA) class I, posted for elective surgeries under monitored anesthesia care were included in the study. Patients with physical status ASA class II and above, posted for emergency surgeries, pregnant patients and patients not willing to participate in the study were excluded from the study. The study protocol was explained to all patients and informed valid consent was obtained. No premedication was given to any patient. Patients were randomly divided into four groups by block randomization method with a block size of four depending on the flow rate they would receive. All the patients were monitored with Planet 60/Star 60 monitor, SANKRAY Technologies Pvt. Ltd., India. Before the start of the study, CO\(_2\) calibration was done with manufacturer approved kit containing calibration gas from Scott medicals. The calibration gas contained 5% of CO\(_2\), 21% of oxygen and the balance amount of nitrogen gas. Autocalibration was done by the machine and its status was confirmed before connecting to each subject. After shifting the patient to the operation theater, the monitor was switched on. Monitor alarms for all the parameters were disabled. Once the autocalibration was over and CO\(_2\) ready message was displayed, it was connected to the patient through nasal prongs of the disposable Adult CapnoLine (Microstream Technology). SpO\(_2\) probe and noninvasive blood pressure (NIBP) were connected. Pulse rate (PR)/min, NIBP, systolic/diastolic as mmHg, RR/min, EtCO\(_2\) as mmHg, FiCO\(_2\) as mmHg, IPI as number were noted at baseline before connecting to Hudson mask. Then the disposable adult Hudson mask (HUDSON RCI, Romsons) was applied with as much as possible seal. The mask was connected to the oxygen source behind workstation, which was out of the vision of monitoring anesthesiologist, through two-meter long tubing. The oxygen was given through flow meter with rotating type bobbin by operation theater assistant, who did not have visual access to the monitor facing opposite side. Oxygen flow rate was started depending on the group. Group I received flow of 3 L/min, Group II received flow of 4 L/min, Group III received 5 L/min of flow, and Group IV received 6 L/min of flow. After starting oxygen through Hudson mask, PR, NIBP, EtCO\(_2\), RR, FiCO\(_2\), and IPI were monitored every minute for 10 min. At the end of 10 min, oxygen mask was removed, and that point was taken as a study endpoint. The study protocol was handed back to the investigator in sealed envelope. After that scheduled surgical procedure was done as planned for each patient. All the patients were monitored with the same planet 60/star 60 machine by the consultant anesthesiologist assigned to the particular case.

**Statistical analysis**

Sample size calculation was done with the primary aim of finding flow with zero inspired CO\(_2\) extrapolating the results from the previous study. Applying the effect size (es-1.98) to the analysis of variance (ANOVA) between four groups the sample size of 8 per group was needed with 1% of significance and power of 95%. Ten patients per group were included to allow possible dropouts. Statistical analysis was done with IBM Statistical Package for Social Sciences version 23 (SPSS; IBM Corporation, USA) for Windows (Microsoft Corporation, USA). Demographic characteristics were assessed with ANOVA and expressed as mean ± standard deviation and frequency. Vital parameters and capnographic parameters were assessed by Kruskal–Wallis test to compare between the groups and expressed as median (range). All the parameters were compared as values noted each minute in between the groups. \(P < 0.01\) was considered statistically significant. The correlation between FiCO\(_2\) and RR was established using Pearson correlation coefficient and was expressed as graphical presentation. The graphs of median values of FiCO\(_2\) and EtCO\(_2\) against each minute of time interval were obtained.

**Results**

The demographic characteristics [Table 1] in all the groups were comparable. All the four groups showed rebreathing of CO\(_2\) as FiCO\(_2\) value was more than zero during the study interval. The baseline FiCO\(_2\) value was zero in all the groups. The amount of FiCO\(_2\) seen in all the groups is comparable [Table 2]. Amount of FiCO\(_2\) during each minute in all four groups is compared in graphical manner [Figure 1]. The graph appears to show high

| Parameter          | Group I  | Group II | Group III | Group IV | \(P\)  |
|--------------------|----------|----------|-----------|----------|--------|
| Age (mean±SD)      | 32.5±10.12 | 30.5±8.30 | 28.3±8.32 | 26.6±6.39 | 0.47   |
| Weight (mean±SD)   | 56.6±11.13 | 54.1±12.46 | 57.1±10.21 | 56.2±10.14 | 0.89   |
| Height (mean±SD)   | 162.5±7.94 | 160.9±6.22 | 162.7±6.36 | 163.9±7.44 | 0.91   |
| Sex (\(n\))        | Male: 6   | 6        | 6         | 5        | 0.96   |
|                    | Female: 4 | 4        | 4         | 5        |        |

SD=Standard deviation
amount of FiCO₂ in Group I as compared to other groups and is above 1 mmHg throughout study interval, however, \( P \) value is not significant. \( P \) values of all capnographic parameters at each minute were not significant [Table 2]. The EtCO₂ values [Figure 2] for all groups were comparable with no statistical significance.

The correlation between RR and FiCO₂ varies among the groups [Figure 3]. In Group I (3 L/min of flow rate), strong positive correlation was seen between FiCO₂ and RR, showing an increase in amount of FiCO₂ with an increase in RR. In Group II, significant negative correlation was seen throughout the study. In Group III except for 3rd and 4th min of study, there was a significant negative correlation. In Group IV, initial 2 min of the study showed significant positive correlation, 3rd min onwards significant negative correlation between FiCO₂ and RR was noted. All hemodynamic parameters and IPI values [Table 3] were comparable with a nonsignificant \( P \) value.

**Discussion**

In this study, we have found that rebreathing is seen at all the flow rates while breathing through Hudson mask and the actual fraction of inhaled CO₂ shown by capnography, at different flow rates is not significant. To the best of our knowledge, this is the first study to compare the actual fraction of inspired CO₂ with the help of capnography, while breathing through Hudson mask. Hudson mask is a variable performance device; hence, FiO₂ varies based on RR and tidal volume (TV). Fresh gas flow (FGF) set as flow rate is delivered lesser than PIFR and so the atmospheric air drawn through the vents is must for adequate TV. This results in breath-to-breath variation in performance of Hudson mask. Our results show that at different flow rates given through Hudson mask, the hemodynamic parameters, SpO₂, and EtCO₂ are comparable.

Jensen *et al.* studied the effect of different oxygen flow rates on ventilation and concluded that at flow rates <5 L/min, there was an increase in TV which they attributed to CO₂ rebreathing. However, they did not find a significant increase in RR at flow rates <5 L/min.⁶ We have studied the actual amount of CO₂ rebreathing and found FiCO₂ and RR both were same at all flow rates. They also noted that rebreathing does not cause any change in hemodynamic parameters. In our study, we did not find any difference in hemodynamic variables as well as IPI. After studying the performance of Hudson type mask at two different flow rates, Leigh concluded that the total expiratory time which represents the O₂ wash in and CO₂ washout time would decide the composition of next breath.⁷ In our study, we found that at lower FGF of 3 L/min, increase in RR resulted into less time for exhaled CO₂ washout leading to increase in FiCO₂. However, FGF of more than 4 L/min was sufficient to

**Table 2: Respiratory parameters at each minute (**\( P \) value)**

| Time interval (min) | EtCO₂ mmHg (\( P \)) | FiCO₂ mmHg (\( P \)) | RR (\( P \)) | SpO₂ (\( P \)) |
|---------------------|-----------------------|-----------------------|-------------|--------------|
| 1                   | 0.57                  | 0.19                  | 0.99        | 0.44         |
| 2                   | 0.55                  | 0.64                  | 0.73        | 0.56         |
| 3                   | 0.77                  | 0.17                  | 0.92        | 0.56         |
| 4                   | 0.94                  | 0.71                  | 0.61        | 0.39         |
| 5                   | 0.83                  | 0.34                  | 0.81        | 0.39         |
| 6                   | 0.91                  | 0.11                  | 0.99        | 0.39         |
| 7                   | 0.43                  | 0.31                  | 0.83        | 0.56         |
| 8                   | 0.62                  | 0.63                  | 0.92        | 1.00         |
| 9                   | 0.79                  | 0.09                  | 0.81        | 1.00         |
| 10                  | 0.75                  | 0.09                  | 0.80        | 1.00         |

**Table 3: Hemodynamic parameters (**\( P \) value)**

| Time interval (min) | PR (\( P \)) | Systolic BP (\( P \)) | Diastolic BP (\( P \)) | IPI number (\( P \)) |
|---------------------|--------------|-----------------------|------------------------|----------------------|
| 1                   | 0.99         | 0.31                  | 0.60                   | 0.18                 |
| 2                   | 0.98         | 0.24                  | 0.67                   | 0.89                 |
| 3                   | 1.00         | 0.43                  | 0.50                   | 0.74                 |
| 4                   | 0.99         | 0.27                  | 0.26                   | 0.83                 |
| 5                   | 0.90         | 0.40                  | 0.55                   | 0.94                 |
| 6                   | 0.95         | 0.20                  | 0.27                   | 0.74                 |
| 7                   | 0.94         | 0.31                  | 0.46                   | 0.47                 |
| 8                   | 0.98         | 0.47                  | 0.28                   | 0.92                 |
| 9                   | 0.88         | 0.25                  | 0.20                   | 0.74                 |
| 10                  | 0.90         | 0.25                  | 0.75                   | 0.98                 |

**Figure 1:** Amount of fractional inspired carbon dioxide in each minute. Fractional inspired carbon dioxide is high at all times at flow rate of 3 L/min

**Figure 2:** Amount of end tidal carbon dioxide during each minute at different flow rates
wash out CO₂ even with decrease in expiratory time. Campkin et al. studied the effects of rebreathing through Hudson mask with the help of capnometry. The load of inspired CO₂ was calculated based on the end tidal CO₂ and the dead space. Their observations showed that some amount of CO₂ was inspired even at FGF of 8 L/min, but it was significantly higher at FGF <4 L/min. In our study also FiCO₂ is seen at all flow rates and though it was higher at FGF <4 L/min it was not significant. However, Campkin et al. have calculated inspired CO₂ load based on EtCO₂ and dead space, while we have analyzed the actual amount of inspired CO₂ during each minute.

At FGF of 3 L/min, FiCO₂ was always above 1 mmHg and at FGF of more than 3 L/min it was always below 1 mmHg. CO₂ rebreathing can stimulate cardiovascular responses but the previous study done on humans for the duration of 10 min has not shown any cardiovascular changes. In our study also FiCO₂ as high as 1 mmHg have not caused any change in hemodynamic parameters and IPI, which is composite index of different vital parameters (EtCO₂, RR, SpO₂, PR). CO₂ tolerance studies have shown that no disabling physiological or clinical symptoms are associated with breathing of 5% CO₂, which is equivalent to a concentration of CO₂ in expired gases.

Campkin et al. found no relation between FiCO₂ and duration of respiratory cycle and concluded that expiration time affecting FiCO₂ is a theoretical possibility. In this study, we found a strong correlation between these parameters. Study by Campkin et al. was done on mechanical lung model, and our study was on spontaneously breathing patients. The physiological variations seen in patients could be responsible for the difference in observations in our study. Previous studies on Hudson mask have mentioned about comparable PaCO₂ at different flow rates. In our study, we did not analyze blood gases, instead measured the EtCO₂ which is a surrogate marker of PaCO₂ under normal physiological conditions and a noninvasive, simple method as well. There was no change in EtCO₂ at different flow rates in our study.

Wagstaff and Soni have concluded that increase in RR causes decrease in effectively inspired oxygen concentration (EIOC) while breathing through Hudson mask. Patient factors such as RR and TV directly affect the EIOC and FiCO₂ irrespective of FGF. All the previous studies regarding performance and FGF in Hudson mask were done either on simulating models or on human volunteers and methods to alleviate patient factors which can affect performance have not been tried. Another limitation of our study is that only capnographic parameters were analyzed and breathing pattern was not evaluated. Further studies are needed on patients or human volunteers after adequate anxiolysis and sedation to minimize the interference of physiological variation.

Conclusions

FiCO₂, the amount of rebreathing is similar at all flow rates while breathing through Hudson mask.

The flow of 3 L/min can be given through Hudson type face mask. Although the amount of inhaled CO₂ while using Hudson type mask appears to be safe, further studies are needed to justify continuing use of Hudson type mask against better-performing oxygen delivery devices.

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Conflicts of interest

There are no conflicts of interest.

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