Superiority of OxyMask™ with Less Carbon Dioxide Rebreathing in Children

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Short Report

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Abstract

Despite the growing importance of oxygen-delivery devices worldwide, there are only a few reports of physiological data on various oxygen masks in children. OxyMask Kid^{TM} (Southmedic Inc. Canada; hereafter OxyMask) is expected to reduce carbon dioxide rebreathing even at low oxygen flow rates because of its structural features. Biological data using OxyMask in children have not been well investigated. Measured respiratory parameters of OxyMask with those of a simple oxygen mask in healthy children were compared. Ten subjects were enrolled, with a median age of 5.4 years. All of them used both OxyMask and a simple oxygen mask. The fraction of inspiratory oxygen (F_IO_2), partial pressure of inspiratory carbon dioxide (P_ICO_2), and partial pressure of end-tidal carbon dioxide were measured using a side-stream gas-sampling monitor in all subjects. The oxygen-flow rate was set at 1, 3, 5, and 10 L/min. F_IO_2 levels were higher with OxyMask than with the simple oxygen mask at 3L/min of oxygen. P_ICO_2 levels were significantly lower with OxyMask than with the simple oxygen mask (1.5 mmHg vs. 3.7 mmHg at 1 L/min, P = .005; 1.0 mmHg vs. 2.7 mmHg at 3 L/min, P = .005, respectively), whereas P_ICO_2 levels were higher at low oxygen-flow rates with both masks.

Conclusion

Our results showed that higher F_IO_2 and less CO_2 rebreathing were achieved with OxyMask than with a simple oxygen mask at low-flow rates of oxygen in healthy children.

What Is Known

- OxyMask is expected to reduce carbon dioxide rebreathing even at low oxygen flow rates because of its structure.
- Efficacy has been shown in experimental models and adult data, but clinical data on use of the OxyMask in children are limited.

What Is New

- Higher fraction of inspiratory oxygen and less carbon dioxide rebreathing were achieved with OxyMask than with a simple oxygen mask at low flow rates of oxygen in healthy children.

Introduction

Administration of oxygen is first-line therapy for respiratory failure. Recently, its importance has been increasing due to the COVID-19 pandemic. Up to 41% of patients with COVID-19 require oxygen therapy [1]. Various oxygen-delivery devices are available for children. High-concentration oxygen is required for children with serious respiratory failure [2]. On the other hand, potential adverse effects of unnecessary high-concentration oxygen are also known[3]. Therefore, it is important to understand the characteristics of oxygen-delivery devices, such as inspired oxygen concentration and washout of carbon dioxide (CO_2)

at various oxygen flow rates. The OxyMask Kid^{TM} (Southmedic Inc. Canada; OxyMask) is a relatively new oxygen-delivery device with a unique structure that can provide high-concentration oxygen by using a diffuser in its inlet, which forms air vortexes that minimize oxygen dilution. Moreover, the unique open-style design of OxyMask reduces CO_2 rebreathing even with a low oxygen-flow rate [4,5]. Although some adult data showing the effectiveness of OxyMask are available, clinical data on use of the OxyMask in children are limited. Thus, we compared the measured inspired oxygen concentrations and CO_2 rebreathing levels in children with OxyMask with those of a conventional simple oxygen mask at various oxygen flow rates.

Method

This study was a prospective open-label crossover study of healthy child volunteers. Written informed consent was obtained from their parents. Ten children aged 1–10 years were recruited between April 2014 and March 2015. OxyMask^{TM} Kid and a conventional simple oxygen mask (Japan Medical Next, Japan) were used in all subjects. This study was conducted with the approval of the ethics committee of our hospital (ethics approval number: rin2014-27).

The data were collected with the subjects seated in an upright position during the measurement procedure. Baseline values were established when the subjects were not wearing the masks, and measurement was started 90 s after they started receiving supplemental oxygen under each condition (oxygen flow rate of 1, 3, 5, and 10 L/min). A side-stream respiratory gas monitor (DS-7300; Fukuda Denshi, Japan) was used, and a sampling tube was inserted into the nasal cavity. Respiratory rate, fraction of inspiratory oxygen (F_IO_2), partial pressure of inspiratory carbon dioxide (P_ICO_2), and partial pressure of end-tidal carbon dioxide ($P_{ET}CO_2$) were obtained three times, and the average was taken under each condition.

For comparisons between the two types of masks, the Wilcoxon signed-rank test was used for count and continuous variables. For comparison between each oxygen flow rate, the Friedman test and Wilcoxon signed-rank test with Bonferroni correction were performed. A two-sided *P* value of <.05 was considered to be indicative of statistical significance. Statistical analysis was performed using SPSS software (IBM SPSS Statistics, Version 21.0. IBM Corp., Armonk, NY).

Results

Ten subjects, three boys and seven girls, completed the study. The median age was 5.4 years (range, 1–10 years), and the median weight was 19.9 kg (range, 12–34 kg). The F_IO_2, P_ICO_2, and $P_{ET}CO_2$ levels and respiratory rates were compared between OxyMask and a simple oxygen mask. As expected, the F_IO_2 levels were increased by oxygen supplementation in a dose-dependent manner in both groups (Fig. 1a). F_IO_2 levels tended to be higher in the OxyMask group than in the simple oxygen mask group and were significantly higher at an oxygen flow rate of 3 L/min ($P = .028$) (Fig. 1b). P_ICO_2 levels were increased

with OxyMask at an oxygen flow rate of 1 L/min (P = .03) and with the simple oxygen mask at rates of 1 and 3 L/min (P = .02, P = .02). P_ICO_2 was significantly lower with OxyMask than with the simple oxygen mask at oxygen flow rates of 1 and 3 L/min (OxyMask vs. simple oxygen mask; 1.5 mmHg vs. 3.7 mmHg at 1 L/min (P = .005), 1.0 mmHg vs. 2.7 mmHg at 3 L/min (P = .005), respectively) (Fig. 1b). P_ICO_2 was also lower in the OxyMask group at an oxygen flow rate of 5 L/min, but the difference was not significant (Fig. 1b). $P_{ET}CO_2$ was significantly higher with a simple oxygen mask than with an OxyMask at an oxygen flow rate of 1 L/min (P = .032), but a consistent pattern was not identified (Fig. 1c). There was no significant difference in respiratory rates between the groups (Fig. 1d).

Discussion

Here, we reported differential characteristics between OxyMask and a simple oxygen mask in children. Our results showed that OxyMask provided a higher concentration of oxygen with lower inspiratory CO_2 than that of a simple oxygen mask, which suggests superior gas exchange efficiency of OxyMask relative to that of the simple oxygen mask.

Administration of high oxygen concentrations is an important function of oxygen-delivery devices. In critically ill children, prompt administration of high-concentration oxygen is essential in the acute phase of treatment [2]. This study showed that the maximum inhaled oxygen concentration was higher in OxyMask than in the simple oxygen mask. According to data from healthy adult volunteers using an OxyMask, the F_IO_2 values were approximately 0.4, 0.6, 0.75, and 0.8 at oxygen doses of 3, 5, 10, and 15 L/min, respectively. Their results were slightly higher than those in our study [4]. This gap may be due to the higher respiratory rate and improper mask fitting in children. Previous simulation studies have shown that mask fitting and the respiratory rate significantly affected F_IO_2 levels [6,7]. Our data are clinically valuable because of the scarcity of actual measurements of F_IO_2 in children. These data can, therefore, be a reference for providing appropriate concentrations of oxygen with an expected F_IO_2.

The issue of rebreathing with low-flow oxygen-delivery devices has been described in previous reports [8]. In the adult cases, a simple oxygen mask increased the minute ventilation rate up to 140% by increasing the tidal volume due to rebreathing at an oxygen flow rate of 3 L/min [8]. In fact, rebreathing of CO_2 was observed with the simple oxygen mask up to 3 L/min of oxygen flow in this study. The simple oxygen mask is widely used in children with respiratory failure. However, the use of a simple oxygen mask in children with ventilation disturbance can lead to CO_2 rebreathing and increased respiratory workload, whereas OxyMask has an advantage over other masks because of less rebreathing, especially with low oxygen flow rates. The results of this study suggest that the OxyMask and simple oxygen mask should be used at flow rates $\geq$ 3 or 5 L/min, respectively, to prevent rebreathing.

OxyMask has an advantage in terms of medical expense. Although high-flow oxygen devices, such as high-flow nasal cannula or venturi masks, are reportedly more effective than a simple facial mask [9,10], introducing expensive oxygen-delivery devices and high rates of oxygen consumption may be a great

burden for developing countries [11]. In the adult study, OxyMask was able to achieve the same level of F_IO_2 at lower oxygen flow rates than those of the Venturi mask [12]. In addition, OxyMask can cover a wide range of F_IO_2 levels without rebreathing even at low oxygen flow rates. Recently, oxygen toxicity with excessive concentrations of oxygen supply has been reported, and it is recommended that the oxygen dose should be appropriately reduced in children [2,3]. Because a simple oxygen mask could not reduce FiO2 without rebreathing, a nasal cannula or other alternative devices would be necessary to achieve appropriate oxygen therapy.

There were several limitations to this study. First, the data were obtained only from healthy children. Thus, it is unclear whether the results can be applied to sick children, such as those with respiratory failure or central nervous system disorders. Second, mask fitting can be an issue. Face masks are designed to be closely fit to the contours of a face. Performance reportedly can greatly depend on how well a mask is fit to an individual [7]. In this study, measurements were performed after natural mask fitting by the children themselves, which may have allowed air leakage from the mask perimeter.

In conclusion, OxyMask achieved significantly higher F_IO_2 with less CO_2 rebreathing at a flow rate of 3L/min of oxygen than those with a simple oxygen mask in healthy children.

Abbreviations

F_IO_2 - fraction of inspiratory oxygen

$P_{ET}CO_2$ - partial pressure of end-tidal carbon dioxide

P_ICO_2 - partial pressure of inspiratory carbon dioxide

Declarations

Funding:

No funding was secured for this study.

Conflicts of interest/Competing interests:

The authors have no potential conflicts of interest to disclose.

Availability of data and material (data transparency):

The datasets used and/or analyzed during the current study are available from the corresponding author on request.

Code availability

N/A

Contributions:

The study was conceived by SO, TT, SS, MN and SK. It was carried out by SO and TT. Analysis was done by SO, SS and MN. Manuscript was written by SO and edited by TT, SS, MN and SK.

Ethics approval:

The study was conducted with the approval of the ethics committee of our hospital (ethics approval number: rin2014-27).

Consent to participate:

Written informed consent was obtained from all individual parents. All the methods were conducted following the relevant guidelines, regulations, and Declaration of Helsinki.

Consent for publication:

Written informed consent was obtained from all individual parents included in the study

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Figures

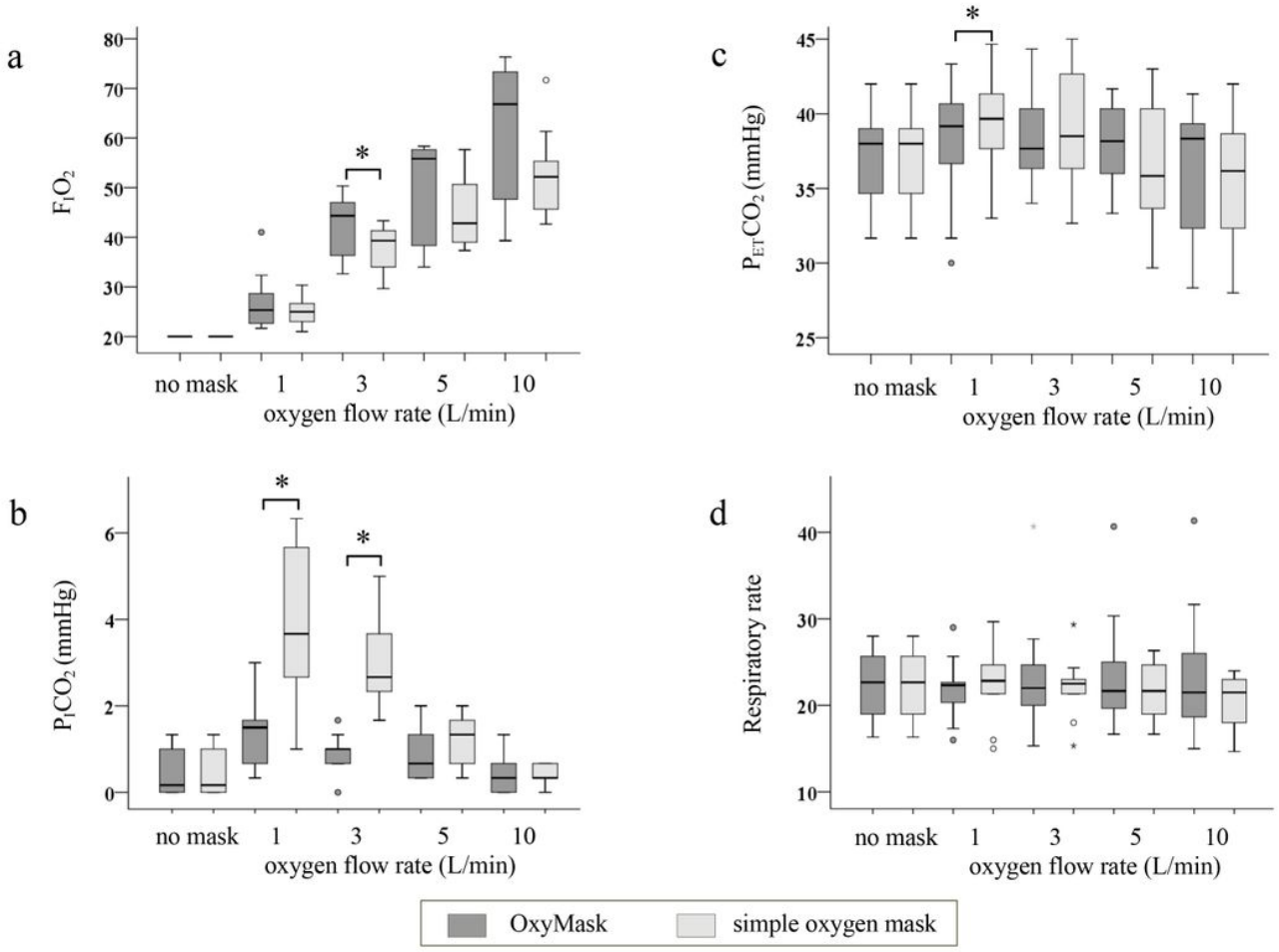

Figure 1

Box plots showing values for no mask and with mask at each oxygen-flow rate. Comparison between OxyMask (dark gray) and simple oxygen mask (light gray). a, FIO2; b, PICO2; c, PETCO2; and d, respiratory rate. *indicates P value <.05, Wilcoxon signed-rank test