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The Efficacy of an Oxygen Mask with Reservoir Bag in Patients with Respiratory Failure

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Background: Oxygen masks with reservoir bags (OMR) are widely used for oxygen therapy in patients with severe respiratory failure. The purpose of the present study was to determine whether OMRs are effectively used in clinical practice.
Methods and Results: In the first phase of the study on the patients with severe respiratory failure, no apparent respiratory motions of the reservoir bag were noted, and the oxygen saturation level as determined by pulseoximetry (SpO_2) did not decrease even after shrinkage of the reservoir bag. In the second phase, when a healthy female volunteer wore an OMR, pressure swings in the reservoir bag were less than 0.1 cmH_2O, even when she was breathing with her maximal respiratory efforts (tidal volume, 1.14 L and respiratory frequency, 19.2 bpm). These pressure swings provoke a less than 50 mL oxygen supply from the reservoir bag. The decreased efficacy of OMR in oxygen therapy may be primarily due to the large space between the OMR and the nose but this space is inevitable in sitting or orthopneic subjects.
Conclusions: Fixing an OMR very tightly to the face is mandatory for its effective use. It should also be kept in mind that there are limitations to the efficacy of OMR, even when they are used with such careful management.

Key words: oxygen therapy, respiratory failure, oxygen supply

INTRODUCTION

Oxygen masks with reservoir bags (OMR) are now widely used for oxygen therapy in patients with severe respiratory failure. The capability of the OMR for providing an oxygen supply in terms of the oxygen fraction (F_IO_2) is described as 0.6 at an oxygen flow rate of 6.0 L/min, 0.8 at 8.0 L/min and 0.9 at 10.0 L/min [1]. In this system, oxygen is supplied to the patient through a one-way valve placed at the inspiratory port, and re-inhalation of the expired gas is inhibited by another one-way valve placed at the expiratory port. If more oxygen is required, oxygen stored in the reservoir bag is inspired by negative pressure generated by the patient's inspiratory efforts. With this mechanism, an OMR can effectively provide high concentration oxygen [2, 3]. However, the proper operation of an OMR is necessary to transmit the patient's respiratory efforts, i.e. negative pressure in the airway, is properly transmitted to the reservoir bag. In other words, bag deflation, together with respiratory efforts, is mandatory for proper use of the OMR. However, physicians and nurses sometimes see that the reservoir bag does not inflate or deflate despite the patient's strong respiratory efforts. The objective of this study was to determine whether an OMR effectively works under ordinary use in the clinical setting.

METHODS

This study consisted of two phases. In the first phase, patients with severe respiratory failure hospitalized in Tokai University Hachioji Hospital were included. If the patient was using an OMR (Oxygen mask three in one, Inspiron- Kobayashi Medical, Tokyo, Japan) and his or her SpO_2 (oxygen saturation on the finger tip) was higher than 90%, the patient was regarded as eligible for this study. After obtaining oral informed consent from each patient, the motion of the reservoir bag was observed, and SpO_2 while using the OMR was measured. Next, the reservoir bag was compressed and fixed so as not to work. During this oxygen shortage period, a physician or nurse checked the patient's general condition and SpO_2 every 5 minutes to ensure the patient's safety. Twenty minutes after shrinkage of the reservoir bag, SpO_2 was again measured.

Before entering the second phase of the study, we measured compliance of the reservoir bag which was inflated with its own elasticity. We further inflated and then deflated the bag using a 50 mL syringe at a frequency of approximately 0.5 Hz.

During the second phase, after obtaining oral informed consent, we measured the respiratory parameters from a healthy female volunteer in the sitting position. This posture simulated the patient's orthopenea. Firstly, the subject wore a mouthpiece, and her tidal volume and respiratory frequency were measured

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Table 1 Oxygen saturation before and after reservoir bag shrinkage

Patient	oxygen supply (l/min)	bag motions	SpO_2 before	SpO_2 after
A	10	no	87%	86%
B	6	no	97%	97%
C	7	no	95%	95%

Table 2 Mean pressure swing in reservoir bag (cmH_2O)

Oxygen Supply (l/min)	respiratory efforts	usually fixed	very tightly fixed
6.0	**quiet breathing**	0.002	0.040
	Maximal effort	0.012	0.110
8.0	**quiet breathing**	0.003	0.030
	Maximal effort	0.008	0.130
10.0	**quiet breathing**	0.002	0.040
	Maximal effort	0.006	0.065

Fig. 1 The positions of the OMR with usual fitting pressure (A) and when fitted very tightly (B) in the sitting position. There was a large space between the nose and the OMR. When the OMR was tightly fitted, a smaller space was still found between the nose and the OMR.

while she was breathing quietly or breathing with her maximal efforts, using with a hot-wire spirometer (RF-H, Minato Medical, Japan). Then she wore an OMR similar to the clinical settings. The respiratory parameters were measured while she was breathing with her maximal efforts. In these trials, the pressure in the reservoir mask was continuously measured (TP-602T, max 5.0 cmH_2O, Nihon Kohden, Japan). Subsequently, an OMR was fixed very tightly to her face and measurements were continued. Oxygen was supplied to the OMR at three different flow rates (6.0, 8.0 and 10.0 L/min). Therefore, a total of 12 oxygen supply conditions were examined (see Table 2).

RESULTS

Although all of the respiratory failure patients were breathing with their strongest efforts, we did not observe apparent expansions and deflations of the reservoir bag. Table 1 shows the effect of the reservoir bag shrinkage on SpO_2. Twenty minutes after shrinkage of the reservoir bag, the SpO_2 did not fall, suggesting that the oxygen supply coming from the reservoir bag was negligible.

In the study of rhythmic inflation and deflation of the reservoir bag using a 50 mL syringe, the pressure in the bag fluctuated with approximately 1.0 cmH_2O amplitude. This suggests that a negative pressure of 1.0 cmH_2O was required to provide 50 mL of oxygen from the bag.

Fig. 1 shows the position of the OMR with the usual fitting (A) and very tight fitting (B) in the healthy volunteer. Since the subject was in a sitting position, while the OMR was fixed in the usual way, it was pulled down by gravity, resulting in a large space between the nose and the OMR. When the OMR was very tightly fitted, she felt slight pain in her cheek, and was quite

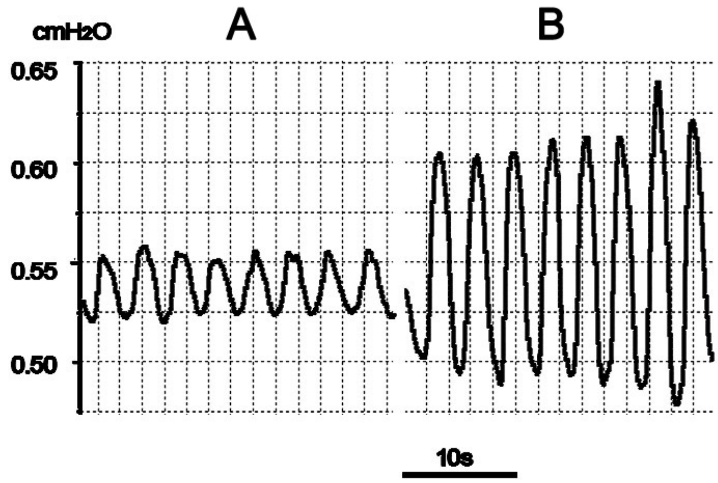

Fig. 2 The bag pressure swings at an oxygen flow rate of 8.0 L/min when the OMR was fixed as usual to the face. The respiratory-related pressure swings in the reservoir bag during quiet breathing were approximately 0.05 cmH_2O (A), and were 0.1 cmH_2O during breathing with maximal effort (B).

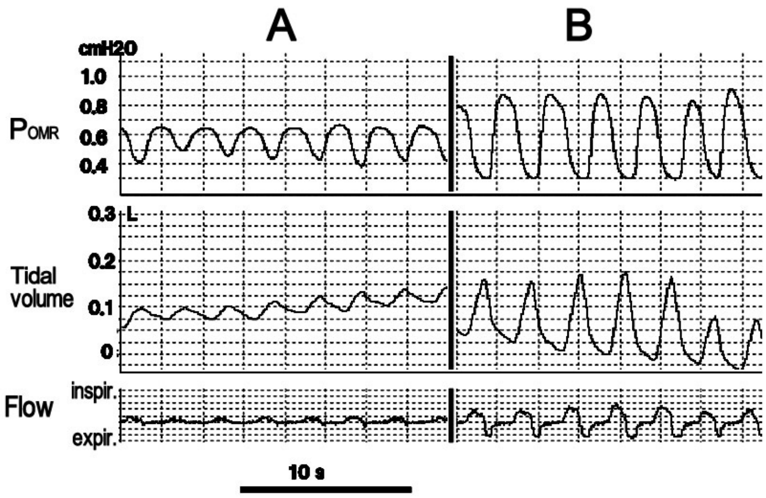

Fig. 3 The bag pressure swings while the OMR was strongly compressed to the face at an oxygen rate of 8.0 L/min. Under this extreme condition, the pressure swings in the reservoir bag were only approximately 0.2 cmH_2O during quiet breathing (A), and approximately 0.5 cmH_2O during breathing with maximal effort (B).

uncomfortable. In this condition, a small space was still found between the nose and the OMR.

When the subject was breathing quietly, her mean tidal volume passed through a mouthpiece was 0.585 L, and her mean respiratory frequency was 14.2 bpm. Thus, her minute ventilation during quiet breathing was estimated to be 8.31 L/min. When the subject breathed with her strongest effort, both tidal volume and respiratory frequency increased to 1.14 L and 19.2 bpm, respectively, and her minute ventilation was three times that observed during quiet breathing.

An example of the bag pressure swings while the oxygen flow rate was 8.0 L/min and the OMR was fixed with usual to the face in the female volunteer was shown in Fig. 2. As shown in panel A, there were respiratory-related pressure swings in the reservoir bag during quiet breathing of approximately 0.05 cmH_2O. When she breathed with maximal effort, amplitude of pressure swings increased, but it was yet 0.1 cmH_2O. Under either condition, no apparent respiratory motions of the reservoir bag were observed.

Table 2 shows the pressure swings in the reservoir bag under the 12 different conditions. When the OMR was fixed as usual, the pressure swings were approximately 0.002 cmH_2O at all three oxygen flow rates examined. When the subject breathed with her maximal efforts, the pressure swings increased to approximately 0.01 cmH_2O. These pressure swings increased when the OMR was tightly fixed. The value was approximately 0.04 cmH_2O during quiet breathing, and was approximately 0.1 cmH_2O during breathing with maximal effort.

Fig. 3 shows a record of the measurements obtained while the OMR was strongly compressed to the face at an oxygen rate of 8.0 L/min. Under this extreme condition, slight motion of the reservoir bag was observed. However, even under this condition, the pressure swings in the reservoir bag were only approximately 0.2 cmH_2O during quiet breathing, and approximately 0.5 cmH_2O during breathing with maximal effort.

DISCUSSION

In the first phase of this study on patients with severe respiratory failure, we found that efficacy of OMRs were not satisfactory. The second phase of the study on a healthy volunteer revealed that an OMR did not work effectively while supplying oxygen if it was not so tightly fixed to the face. In the clinical setting, an OMR often acted as a high-flow nonrebreathing oxygen mask as has been suggested by

Miyamoto (4). In that study, an OMR was used for five young healthy volunteers, and he found that there was a negative effect of the space generated between the OMR and the nose with regard to end-tidal O_2. We confirmed this result in the first phase of the study, and further added a theoretical basis to his study in the second phase.

In examining manual inflation and deflation of the reservoir bag, we found that a negative pressure of 1.0 cmH_2O was required to provide 50 mL of oxygen from the bag. When the healthy volunteer in our study wore an OMR fitted similar to that observed in clinical use, pressure swings in the reservoir bag were approximately 0.01 cmH_2O (Table 2), even when she breathed with maximal effort. This result suggests that oxygen was not inspired from the bag. If the OMR was fixed very tightly to the face, the pressure swings increased, but remained between 0.065 and 0.113 cmH_2O. Even under an extreme "tight fit" condition, the pressure swings in the reservoir bag were approximately 0.5 cmH_2O. Since her tidal volume was estimated as 1.14 L during breathing with maximal efforts, an additional oxygen supply of less than 0.05 L for every breath may be of little benefit.

Boumphrey *et al.* examined the efficacy of an OMR when used in healthy female volunteers [5]. They very carefully fixed the OMR to the face, and oxygen was supplied to the OMR at 15 L/min. Under this condition, they reported that the oxygen supply to the subjects was equivalent to 0.97 inspired oxygen fraction. However, they did not describe whether any rhythmic motion of the reservoir bag was observed.

In conclusion, an OMR may act as a high-flow and non- rebreathing mask while it is loosely fixed to the face. However, for the most effective use of an OMR, it is necessary to fix it very tightly to the face. It should also be kept in mind that efficacy of an OMR is somewhat limited, even if it is used carefully and under optimal conditions.

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