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Ventilator Settings to Avoid Nuisance Alarms During Mouthpiece Ventilation

Annalisa Carlucci MD, Alessio Mattei MD, Veronica Rossi, Elena Paracchini MD, Santi Maurizio Raineri MD, and Cesare Gregoretti MD

BACKGROUND: A recent study found that activation of disconnection and low-pressure alarms is common during mouthpiece ventilation and may represent a major limitation to its use. The aim of this bench study was: (1) to investigate the technical aspects that can influence the setting of the ventilator during mouthpiece ventilation and (2) to provide a practical setting strategy to avoid the alarm activation. METHODS: Eight life-support ventilators able to deliver volume controlled ventilation were tested in a bench study using a single-limb non-vented circuit configuration connected to a standard mouthpiece. Disconnection and apnea alarm were turned off or set at the least sensitive setting. The backup frequency was set at the lowest available level. Different tidal volumes (V_T) (from 500 to 1,200 mL) were tested with the rectangular and descending flow shape. For each V_T, we reported the maximum set inspiratory time (T_I) that allowed preventing activation of the low-pressure alarm. The presence of auto-triggering was also surveyed. RESULTS: We found that a correct combination of V_T and T_I avoided the activation of disconnection and low-pressure alarms in all but 3 ventilators. One ventilator did not allow mouthpiece ventilation independently from the settings used. The inability to turn off the apnea alarm in two other ventilators led to the alarm going off in any tested conditions after 120 s without triggered breaths. Auto-triggering was seldom found and easily worked out, except for in one ventilator. CONCLUSIONS: An appropriate alarm setting and combination of V_T and T_I would allow the majority of the tested ventilators to be used for mouthpiece ventilation without alarm activation. *Key words: noninvasive ventilation; neuromuscular disease; mechanical ventilation; chronic respiratory failure; pulmonary ventilation; mechanical ventilators.* [Respir Care 0;0(0):1–•. © 0 Daedalus Enterprises]

Introduction

Open-circuit mouthpiece ventilation is a type of noninvasive ventilation delivered via a mouthpiece. First used on ventilator-dependent polio patients,[1] over the last few decades, the use of mouthpiece ventilation has significantly increased, mainly in the chronic setting and preferentially in patients suffering from neuromuscular disease.[2] This technique, combined with aggressive mechanically assisted cough, has also been proposed as part of a protocol designed to wean patients from invasive mechanical ventilation after an episode of acute respiratory failure because of a congenital or acquired neuromuscular disease.[3-5] Mouthpiece ventilation is used with single-limb non-vented circuit ventilators in pressure-controlled or, more frequently, in volume-controlled mode for allowing air stacking.[6] The patient can get mouthpiece ventilation

Dr Carlucci, Ms Rossi, and Dr Paracchini are affiliated with Pulmonary Rehabilitation, Fondazione S Maugeri, IRCCS, Pavia, Italy. Dr Mattei is affiliated with the Cardiothoracic Department, Città della Salute e della Scienza-Molinette, Torino, Italy. Dr Raineri and Dr Gregoretti are affiliated with the Department of Biopathology and Medical and Forensic Biotechnologies (DIBIMEF), Section of Anesthesiology, Analgesia, Emergency, and Intensive Care, Policlinico P Giaccone, Palermo, Italy.

Dr Raineri has disclosed a relationship with MSD-Italia. Dr Gregoretti has disclosed relationships with Philips Respironics, Resmed, Covidien, Lindegas, Medicair, Orion, GE, and Air Liquide. The other authors have disclosed no conflicts of interest.

Correspondence: Annalisa Carlucci MD, Pulmonary Rehabilitation Fondazione S Maugeri, IRCCS, Via Maugeri 10, 27100 Pavia, Italy. E-mail: annalisa.carlucci@fsm.it.

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breaths passively, using the set backup frequency on the ventilator, or he/she can actively trigger the breath, retaining a part or all of the delivered volume. As a matter of fact, depending on the ability to move the neck, the patient can continuously keep the mouthpiece between his/her lips or leave it for a variable time.

Despite these attractive features, the practical application of mouthpiece ventilation and the possibility of adapting a ventilator conceived for invasive or noninvasive ventilation to completely open mouthpiece ventilation may pose some technical problems. Some drawbacks like alarm activation and/or the presence of a noisy bias flow during disconnection from the mouthpiece may make it unacceptable for the patient.

A recent study[8] found that alarms (mainly disconnection and low-pressure alarms) were frequently activated during mouthpiece ventilation, becoming a source of nuisance for the user. This can lead to unsuccessful application of mouthpiece ventilation. The aim of this bench study was to test the feasibility of mouthpiece ventilation in volume-controlled mode with home ventilators and give, for each tested ventilator, a practical setting strategy that would allow mouthpiece ventilation to be used without generating nuisance alarms.

QUICK LOOK

Current knowledge

Mouthpiece ventilation use has significantly increased in recent decades. It was first applied in neuromuscular diseases and then extended to other chronic respiratory disorders. However, since it is a mode of ventilation with significant leaks, alarm activation is the most frequently cited technical problem.

What this paper contributes to our knowledge

The majority of available home ventilators may be used for mouthpiece ventilation even in the absence of a specific mode. An appropriate combination of tidal volume and inspiratory time and an appropriate setting of alarms may avoid nuisance alarm activation.

Methods

We tested 8 life-support ventilators, commercially available in Europe, able to deliver assisted volume controlled ventilation: Vivo 50 (Breas, Goteborg, Sweden), Trilogy (Philips Respironics, Murrysville, Pennsylvania), PB560 (Covidien, Mansfield, Massachusetts), Ventilogic LS (Weinmann, Hamburg, Germany), Elisée 150 (ResMed, San Diego, California), Astral 150 (Resmed, San Diego, California), Monnal T50 (Air Liquide, Cambridge, Maryland), and Newport HT70 (Covidien, Mansfield, Massachusetts). The main aim was to test, for each ventilator, the possibility of using mouthpiece ventilation by minimizing nuisance alarms; the secondary outcome was to measure the bias flow exiting from the distal part of the circuit during disconnection from mouthpiece ventilation when the end-expiratory pressure was set to zero.

Ventilators were tested in a single-limb non-vented (expiratory valve) configuration. A 22-mm angled mouthpiece (Philips Respironics, Murrysville, Pennsylvania) was connected to a plastic, corrugated 16 × 2-cm tube inserted from one side directly into the mouthpiece and on the other side to the expiratory valve through a silicon connector and connected to a 22-mm respiratory circuit[9] (Fig. 1). Different tidal volumes (V_T) (from 500 to 1,200 mL) were tested with the rectangular and descending flow shape. For each V_T, we reported the maximum inspiratory time (T_I) that can be set to prevent activation of the low-pressure alarm. As a first step, for any tested V_T, the T_I was progressively increased in steps of 100 ms from the minimum allowed value until a low-pressure alarm was activated. Each value of T_I was kept constant for 3 min to check activation of ventilator alarms. In a second step, for any tested V_T, the T_I was progressively decreased in steps of 100 ms from the maximal allowed value. For both of these steps, the maximum T_I was considered the longest one before activation of the low-pressure alarm. Maximum T_I values were not different between the 2 steps. An inspiratory flow trigger was used in all ventilators except in the Newport HT70 and Elisée 150, where only a pressure trigger is available during volume controlled mode. The low-pressure alarm was set at the minimum available value, according to the manufacturer's specifications. The disconnection and apnea alarms were turned off whenever possible; otherwise, they were set at the least sensitive value. The backup frequency was set at the lowest allowed value, considering that the mouthpiece ventilation user might trigger the ventilator.[8] In this case, reducing the backup frequency would also allow the minimization of continuous flow on the user's face coming from mandatory breaths. For the same reason, we also measured the bias flow at zero end-expiratory pressure during disconnection from mouthpiece ventilation by using a pneumotachograph (model 3700, Hans Rudolph, Inc, Shawnee, Kansas) placed between the mouthpiece and the circuit (Fig. 1). The Trilogy has a mouthpiece ventilation mode where, as a default, all alarms except for the low-pressure alarm are turned off. Moreover, this mode has a very sensitive but unchangeable flow trigger, named the kiss trigger, that is a reverse flow trigger simply activated by closing the lips around the mouthpiece. Because in our clinical practice some patients are not able to activate this trigger, we tested the Trilogy with (mouthpiece ventilation mode) and without (assist

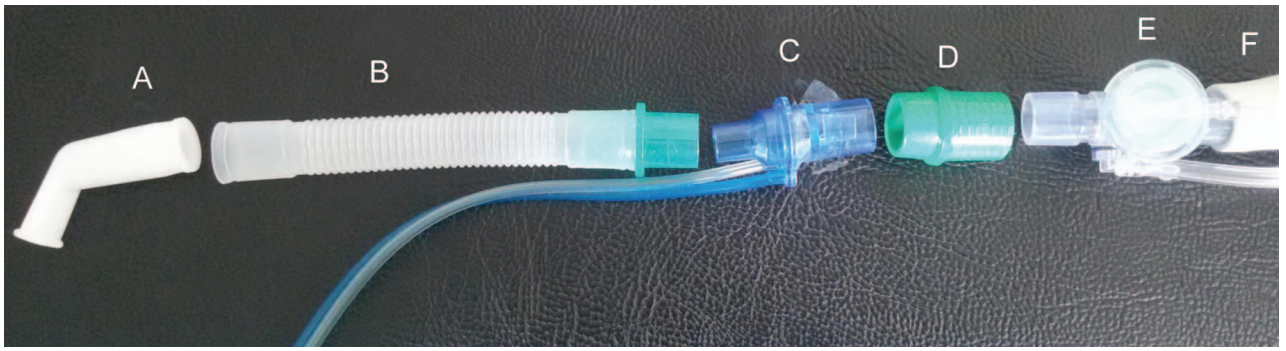

Fig. 1. Mouthpiece ventilation breathing circuit, as described in the text. From left to right: mouthpiece (A), plastic corrugated 16 × 2-cm tube (B), pneumotachograph (C), silicon connector (D), expiratory valve (E), 22-mm respiratory circuit (F). The pneumotachograph was inserted only to measure the bias flow through the circuit.

Table 1. Technical Data for Tested Ventilators

Tested Ventilator	Low-Pressure Alarm (cm H_2O)	Minimum Breathing Frequency Alarm	Minimum Backup Frequency (breaths/min)	Ability to Turn Off the Disconnection Alarm	Ability to Turn Off the Apnea Alarm	Available Inspiratory Trigger in NIV Mode	End-Expiratory Flow at Zero PEEP (L/min)	Ventilator Prescription (*n*)*
V50	1	Off	4	Yes	Yes	Flow	8	3
TRMPV	1	Off	0	Yes	Yes	Kiss Trigger	20–25	2
TRACV	2	Off	0	Yes	Yes	Flow	20–25	2
PB560	2	Off	1	No (max 62 s)	Yes	Flow	18	1
VLS	0.2	Off	5	NA	Yes	Flow	20	3
EL150	NA	NA	2	NA	NA	Pressure	0	2
AS150	Off	Off	0	NA	No (max 120 s)	Flow	15	4
NWHT70	1	Off	1	NA	No (max 120 s)	Pressure	0	1
MT50	1	1	5	NA	No (max 60 s)	Flow	0	2

* Number of simultaneous settings that can be present at once in the same ventilator.
NIV = noninvasive ventilation
V50 = Vivo 50
TRMPV = Trilogy with mouthpiece ventilation module
TRACV = Trilogy without mouthpiece ventilation module (with assist control ventilation)
VLS = Ventilogic LS
NA = not available option
EL150 = Elisée 150
AS150 = Astral150
NWHT70 = Newport HT70
MT50 = Monnal T50

control ventilation mode) the mouthpiece ventilation configuration.

Results

Technical data for the tested ventilators are shown in Table 1. The low-pressure alarm can be turned off only in the Astral 150; for the other ventilators, it can be set from 0.2 (with the Ventilogic LS) to 2 cm H_2O (with the Trilogy assist control ventilation mode and the PB560). The Elisée 150 does not allow us to adjust a low-pressure alarm, which is, therefore, predefined. The disconnection alarm can be switched off in the Vivo 50 and Trilogy; the apnea alarm can be switched off in the Vivo 50, Trilogy, PB560, Elisée 150, and Ventilogic LS; the backup frequency can be set at 0 breaths/min with the Trilogy mouthpiece ventilation mode and the Astral 150; in the other ventilators, the minimum backup frequency ranged from 1 breath/min with the PB560 and Newport HT70 to 5 breaths/min with the Monnal T50 and Ventilogic LS. However, with the Vivo 50, T_I depends not only on the set volume but also on the backup frequency (Table 2). For the lowest volumes and backup frequency, the minimum adjustable T_I was too long to avoid the low-pressure alarm. For example, for a V_T of 500 mL and a backup frequency of 4, the minimum adjustable T_I was 1.4 s, which caused the alarm to be activated. A reduction of T_I was achieved only by increasing the backup frequency. As shown in Table 1, even with

Table 2. Practical Combination of V_T and T_I Settings to Avoid the Activation of Disconnection and Low-Pressure Alarms

V_T (mL)	V50		PB560		TRACV		TRMPV		VLS		EL150		NWHT70		AS150	
	Max T_I* (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)	Max T_I (s)	Min Backup Frequency (breaths/min)
Dfs																
500	0.6	10	0.6	1	1.3	0	4.2	0	2.4	5	1.0	2	1.4	2	3	0
600	0.8	7	0.7	1	1.5	0	4.2	0	2.4	5	1.3	2	1.6	2	3	0
700	0.9	7	0.8	1	1.6	0	4.2	0	2.4	5	1.5	2	1.9	2	3	0
800	1.1	5	0.9	1	1.8	0	4.2	0	2.4	5	1.8	2	2.2	2	3	0
900	1.2	5	1.1	1	1.9	0	4.2	0	2.4	5	2.0	2	2.5	2	3	0
1,000	1.3	5	1.2	1	2.1	0	4.2	0	2.4	5	2.3	2	2.8	2	3	0
1,100	1.5	4	1.3	1	2.2	0	4.2	0	2.4	5	2.4	2	3	2	3	0
1,200	1.7	4	1.4	1	2.4	0	4.2	0	2.4	5	2.7	2	3	2	3	0
Rfs																
500	0.7	8	0.6	1	1.1	0	4.2	0	2.4	5	0.7	2	1.1	2	3	0
600	0.9	7	0.6	1	1.2	0	4.2	0	2.4	5	0.8	2	1.3	2	3	0
700	1.0	5	0.7	1	1.3	0	4.2	0	2.4	5	1.0	2	1.5	2	3	0
800	1.1	5	0.8	1	1.4	0	4.2	0	2.4	5	1.1	2	1.7	2	3	0
900	1.3	4	0.9	1	1.5	0	4.2	0	2.4	5	1.3	2	2	2	3	0
1,000	1.5	4	1.0	1	1.6	0	4.2	0	2.4	5	1.4	2	2.2	2	3	0
1,100	1.6	4	1.1	1	1.7	0	4.2	0	2.4	5	1.5	2	2.4	2	3	0
1,200	1.7	4	1.2	1	1.9	0	4.2	0	2.4	5	1.6	2	2.5	2	3	0

* Maximum inspiratory time that prevents the low-pressure or disconnection alarm.
† Minimum backup Frequency that allows the maximum inspiratory time setting without generating the low-pressure alarm. Data regarding the Monnal T50 are not reported because the disconnection alarm was always activated, irrespective of the inspiratory time and tidal volume set.
V50 = Vivo 50
TRMPV = Trilogy with mouthpiece ventilation module
TRACV = Trilogy without mouthpiece ventilation module (with assist control ventilation)
VLS = Ventilogic LS
EL150 = Elisée 150
NWHT70 = Newport HT70
AS150 = Astral 150
Dfs = descending flow shape
Rfs = rectangular flow shape

end-expiratory pressure set to zero, a variable level of bias flow was measured at the end of the circuit between mandatory breaths. It was very low or absent in the Vivo 50, Elisée 150, Monnal T50, Newport HT70, and Astral 150, but it reached 20 L/min with the PB560 and Ventilogic LS and 25 L/min with the Trilogy. With the Trilogy assist control ventilation mode and the Monnal T50, a small decrease in trigger sensitivity was needed to avoid auto-triggering. Irrespective of trigger sensitivity, auto-triggering was always present with the Astral 150. Table 2 shows a practical setting to avoid the activation of disconnection or low-pressure alarms. As clearly shown, with the Vivo 50 and PB560, a T_I higher then 1 s is not allowed without generating alarm activation with volumes from 500 to 800 mL. In the Monnal T50, the disconnection alarm was activated at any combination of V_T and T_I.

Discussion

The main results of the present bench study are: (1) all tested ventilators, except for the Monnal T50, can be used for mouthpiece ventilation, even in the absence of a specific mode; (2) an appropriate combination of V_T, T_I, and, for one ventilator, backup frequency, may avoid disconnection or low-pressure alarm activation of all ventilators but one (Monnal T50); (3) even when the end-expiratory pressure is set to zero, some ventilators have a high bias flow exiting from the distal part of the circuit during the user disconnection; and (4) auto-triggering is seldom found and easily prevented, except in the Astral 150.

Mouthpiece ventilation in volume-controlled mode is widely used in neuromuscular disease even in fully ventilator-dependent patients.[6] More recently, mouthpiece ventilation use has been shown to treat moderate respiratory acidosis in exacerbation of COPD, showing a reduction in the endotracheal intubation rate in comparison with standard medical therapy[7], and a non-inferiority to nasal mask in preventing further deterioration of gas exchanges.[10]

However, mouthpiece ventilation application is based on the experience of only a few centers,[11] and alarm activation is a frequent drawback.[8] Strategies for avoiding alarm activation may be clinically important. Nowadays, only the Trilogy offers a dedicated platform for mouthpiece ventilation. Nevertheless, in a period of economic burden, possibilities for adapting commercially available ventilators to mouthpiece ventilation should be encouraged.

The main alarms to consider during mouthpiece ventilation in volume-target mode are apnea, low-pressure, and disconnection alarms. An apnea alarm indicates the absence of a breath activated by the patient. When it cannot be switched off (as in the Monnal T50, Newport HT70, and Astral 150), it is activated if the mouthpiece ventilation user does not breathe for a time longer than the set apnea alarm (60 or 120 s). A disconnection alarm works in the same way as the low-pressure alarm, and both are activated when the pressure in the circuit does not reach the set low-pressure alarm. This is likely to happen when the mouthpiece ventilation user can remain disconnected from the ventilator for several minutes, and the backup rate cannot be set to zero, delivering mandatory breaths, or when auto-triggering occurs.

In our study, we showed that an accurate combination of V_T and T_I is the key factor in avoiding alarm activation. In their bench study, Khirany et al[8] tested the performance of mouthpiece ventilation with 6 home-care ventilators by connecting ventilators to a test lung and simulating an adult and pediatric profile. They showed that none of the tested ventilators were able to deliver mouthpiece ventilation without alarms and/or auto-triggering or ineffective triggering. However, they tested only 2 volumes (500 and 1,000 mL) and one T_I whose value was not reported. In addition, the ventilators were tested with the lowest number of mandatory machine breaths necessary to prevent activation of the disconnection alarm. We agree that the backup rate should be set at the minimum available value to significantly reduce the discomfort due to continuous flow on the user's face during mouthpiece disconnection. However, we found that in one ventilator (the Vivo 50), setting the backup rate and volumes at the lowest values did not allow us to set a T_I low enough to prevent alarm activation. In fact, with the Vivo 50, T_I depends not only on the tidal volume but also on the backup rate. This means that for the lowest tested V_T at the lowest backup rate, the minimum T_I allowed was already too long for avoiding low-pressure alarms. A decrease in the T_I can be obtained only by increasing the backup rate. This is due to an internal algorithm that links the T_I, V_T, and backup rate to ensure that the inspiratory-expiratory ratio and, consequently, the peak inspiratory flow is maintained in a predefined range. As a consequence, the possible relationship between the backup rate and the maximum T_I value should be taken into account when setting mouthpiece ventilation with this ventilator.

Auto-triggering was seldom found and easily fixed except in the Astral 150. Boitano and Benditt[9] found that 6 of 8 tested volume-target ventilators could support mouthpiece ventilation. However, they speculated that ventilators should have a pressure trigger to avoid auto-triggering. Nowadays, the majority of home ventilators available in Europe have only a flow trigger (Table 1) option when the noninvasive ventilation mode is chosen. Because new algorithms for leak compensation have been developed, only minimal problems of auto-triggering have been found in our study.

As shown in Table 1, even when the end-expiratory pressure was set to zero, some ventilators have a bias flow exiting the circuit. This variable must be taken into con-

sideration when choosing a ventilator for mouthpiece ventilation because it could be a source of discomfort in users who cannot move their head.

In a recent clinical and bench study aimed at surveying the practice of mouthpiece ventilation and at evaluating the performance of ventilators for mouthpiece ventilation, Khirany et al[8] showed that >70% of subjects treated with mouthpiece ventilation used it in volume controlled mode. The majority whereas several types used the same ventilator during night and day but with different settings. This result underlines the usefulness of having more than one simultaneous setting, called ventilator prescription, in a single ventilator unit. Interestingly, as shown in Table 1, all ventilators, except for the Newport HT70 and PB560, allow more than one ventilator prescription (eg, one for mask ventilation and the other for mouthpiece ventilation).

Our study presents some limitations. First, we tested just one type of mouthpiece, whereas several types are available with different internal resistances. However, the aim of the study was not to test different mouthpieces but rather to survey the possibility of using mouthpiece ventilation without nuisance alarms in the majority of home ventilators available in Europe. Because the most frequent alarm (low-pressure alarm) depends on both the ventilator setting and the mouthpiece resistances, we chose to use the angled one with the highest size (22 mm) that offers the lowest resistances and, consequently, more limitations in the range of adjustable T_I. Smaller mouthpieces would allow a further increase in T_I for a given V_T before leading to the alarm activation. Second, we did not test the single limb vented circuit configuration because it requires a minimum value of end-expiratory pressure up to 3–4 cm H_2O (except for the Trilogy mouthpiece ventilation mode), thus generating a continuous uncomfortable flow. Last, we do not have any information about the inspiratory trigger sensitivity and its patient perception. We do not think that trigger sensitivity could be easily tested in vitro during mouthpiece ventilation because of the difficulty of simulating the variability of leaks and the effort of different patients.

Conclusions

This study makes the operators aware of the possibility of using mouthpiece ventilation with the majority of the tested ventilators. A correct combination of V_T and T_I avoided activation of the low-pressure alarm when the user was disconnected from the circuit.

REFERENCES

1. Affeldt JE. Roundtable conference on poliomyelitis equipment: New York City, May 28-29, 1953. White Plains, New York: National Foundation for Infantile Paralysis, March of Dimes; 1953.
2. Toussaint M, Steens M, Wasteels G, and Soudon P. Diurnal ventilation via mouthpiece: survival in end-stage Duchenne patients. Eur Respir J 2006;28(3):549-555.
3. Bach JR. New approaches in the rehabilitation of the traumatic high level quadriplegic . Am J Phys Med Rehabil 1991;70(1):13-19.
4. Bach JR. Amyotrophic lateral sclerosis: prolongation of life by noninvasive respiratory AIDS. Chest 2002;122(1):92-98.
5. Bach JR, Gonçalves MR, Hamdani I, Winck JC. Extubation of patients with neuromuscular weakness: a new management paradigm. Chest 2010;137(5):1033-1039.
6. Bach JR. Continuous noninvasive ventilation for patients with neuromuscular disease and spinal cord injury. Semin Respir Crit Care Med 2002;23(3):283-292.
7. Glerant JC, Rose D, Oltean V, Dayen C, Mayeux I, Jounieaux V. Noninvasive ventilation using a mouthpiece in patients with chronic obstructive pulmonary disease and acute respiratory failure. Respiration 2007;74(6):632-639.
8. Khirani S, Ramirez A, Delord V, Leroux K, Lofaso F, Hautot S, et al. Evaluation of ventilators for mouthpiece ventilation in neuromuscular disease. Respir Care 2014;59(9):1329-1337.
9. Boitano LJ, and Benditt JO. An evaluation of home volume ventilators that support open-circuit mouthpiece ventilation. Respir Care 2005;50(11):1457-1461.
10. Nicolini A, Santo M, Ferrari-Bravo M, Barlascini C. Open-mouthpiece ventilation versus nasal mask ventilation in subjects with COPD exacerbation and mild to moderate acidosis: a randomized trial. Respir Care 2014;59(12):1825-1831.
11. Bach JR, Alba AS, Saporito LR. Intermittent positive pressure ventilation via the mouth as an alternative to tracheostomy for 257 ventilator users. Chest 1993;103(1):174-182.