

An Evaluation of Home Volume Ventilators That Support Open-Circuit Mouthpiece Ventilation

Louis J Boitano MSc RRT and Joshua O Benditt MD

BACKGROUND: Open-circuit mouthpiece ventilation (MPV) is a form of noninvasive ventilation that can be used to provide portable daytime ventilatory support for neuromuscular patients with chronic respiratory failure. MPV has been reported to reduce the risk of respiratory infection due to tracheostomy, and to improve cough and voice function and patient quality of life. Despite these potential benefits, mouthpiece ventilation is not widely used. This may be due in part to the fact that little information is available as to which ventilators can support this application. **OBJECTIVE:** To determine which volume-cycled portable home ventilators currently available in the United States will support MPV, and what peak inspiratory flow rates create adequate circuit pressure to prevent low-pressure alarming. **METHODS:** We used a commercially available MPV breathing circuit with a set tidal volume range of 500–1,000 mL with each of 8 ventilators currently available in the United States. **RESULTS:** Six of the 8 ventilators supported MPV: Respironics Lifecare PLV-100 and PLV Continuum, Mallinckrodt Achieva PSO2, Pulmonetics LTV800, Newport HT50, and Uni-Vent Eagle 754. *Key words:* noninvasive ventilation, neuromuscular disease, volume-cycled ventilator, mouthpiece ventilation. [Respir Care 2005;50(11):1457–1461. © 2005 Daedalus Enterprises]

Introduction

The use of MPV, also called “sip ventilation,” was first reported at a conference on post-polio myelitis respiratory equipment in 1953, where John E Affeldt of Rancho Los Amigos Hospital in Los Angeles observed that an intermittent positive-pressure ventilation machine with a mouthpiece circuit could be used to relieve dyspnea in ventilator-dependent polio patients whose negative-pressure ventilation was interrupted for transfers, nursing care, or physical therapy.¹ Since that time, MPV has been reported to reduce the risk of respiratory infection due to tracheos-

tomy, and to improve cough, voice function, and patient quality of life.^{2–5}

Currently available portable volume-cycled ventilators have low-pressure alarms that sound when circuit pressure drops, indicating a tubing disconnection. Normally, open-circuit ventilation cannot be performed because of low-pressure alarming. Open-circuit MPV can be performed when sufficient peak inspiratory flow (PIF) is used to create enough back-pressure (2–3 cm H₂O) against the flow-limiting mouthpiece (Fig. 1) to prevent low-pressure alarming in an open-circuit system (Fig. 2). When the set ventilator breath rate in the assist/control mode is sufficient to prevent apnea alarming, the ventilator circuit can remain open for extended periods without either low-pressure or apnea alarming. The patient can receive a ventilator-assisted breath as often as needed by making a “sip” effort through the mouthpiece, triggering the ventilator. This allows the patient to receive as much noninvasive ventilatory support as needed. In addition, volume-cycled ventilation allows the user to take multiple breaths (breath-stacking maneuvers) without exhaling, increasing the vital capacity.^{3,6,7} By making a cough effort with MPV-supported hyper-inflated lung volumes, a neuromuscular patient who has little or no effective cough strength can

Louis J Boitano MSc RRT and Joshua O Benditt MD are affiliated with the Department of Respiratory Care, Division of Pulmonary and Critical Care Medicine, and the Northwest Assisted Breathing Center, University of Washington Medical Center, Seattle, Washington.

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Correspondence: Louis J Boitano MSc RRT, University of Washington Medical Center, Box 356166, 1959 NE Pacific Street, Seattle WA 98195. E-mail: boitano@u.washington.edu.



Fig. 1. Mouthpiece with angular restriction and oral flange.

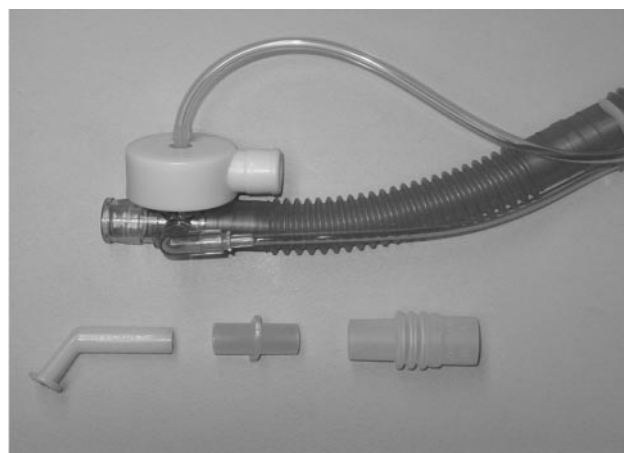


Fig. 3. Mouthpiece ventilation breathing circuit components.

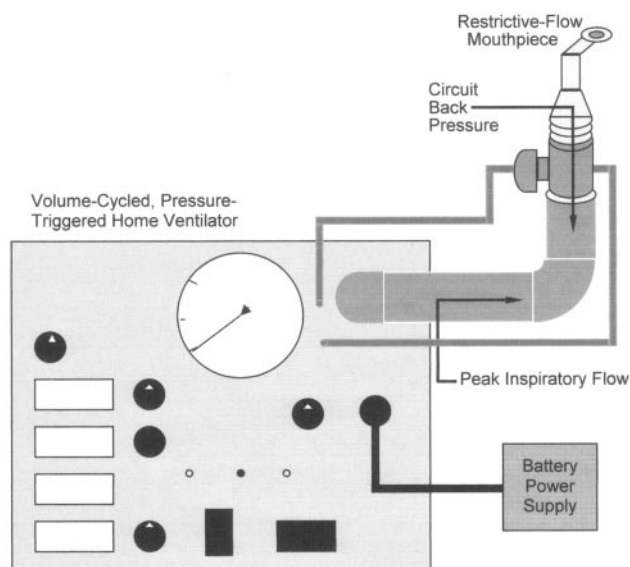


Fig. 2. Open-circuit mouthpiece system as tested with 8 models of volume-cycled pressure-triggered portable home volume ventilator.

utilize the stored recoil energy of the hyper-expanded chest wall to produce a higher expiratory flow rate, sufficient to clear pulmonary secretions as often as needed.^{5,8} MPV can provide independent and portable noninvasive respiratory support through hyper-inflation and cough augmentation, as well as provide adequate ventilation in a state of either stable or progressive neuromuscular respiratory insufficiency.

The purposes of this study were to identify (1) which of the volume-cycled, pressure-triggered home ventilators currently available in the United States support MPV and (2) what PIFs are necessary to prevent low-pressure alarming when using a commercially available MPV breathing circuit at set tidal volumes of 500–1,000 mL.

Methods

The following pressure-triggered, volume-cycled portable home ventilators were evaluated in this study, based on availability of testing at the time of the study: PLV-100 and PLV Continuum (Respironics, Murrysville, Pennsylvania), Achieva and LP10 (Mallinckrodt, Minneapolis, Minnesota), LTV800 (Pulmonetic Systems, Minneapolis, Minnesota), HT50 (Newport Medical Instruments, Newport Beach, California), Uni-Vent Eagle model 754 (Impact Instrumentation, West Caldwell, New Jersey), and iVent 201 (VersaMed, Pearl River, New York). Only volume-cycled, pressure-triggered home ventilators were tested, as it was known from previous testing that flow-triggered volume-cycled home ventilators could not be prevented from auto-triggering when tested using an open-circuit MPV breathing system.

The same type of commercially available open breathing circuit was used to evaluate all the tested ventilators. The breathing circuit consisted of an adult single-lead home-ventilator breathing circuit (Fig. 3) (catalog part 001795, Allegiance Healthcare, McGaw Park, Illinois), a 5-cm × 22-mm × 15-mm flexible silicon tube adaptor fitted to the distal circuit end of the exhalation valve body (catalog part 06484, Respironics, Murrysville, Pennsylvania), and a 15-mm angled mouthpiece (catalog part 1004524, Respironics, Murrysville, Pennsylvania). A plastic 15-mm inner-diameter × 22-mm outer-diameter, breathing-circuit adaptor (part C50-177078, Tri-Anim, Sylmar, California) was used to attach the angled plastic mouthpiece to the flexible silicon tube. Each ventilator was tested in the assist-control mode, using the lowest number of mandatory machine breaths necessary to prevent apnea alarming, based on the respective manufacturer's specifications. The minimum PIF necessary to prevent low-pressure alarming was then determined for set ventilator tidal volumes, in

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Table 1. Comparison of Home Volume Ventilator Specifications for Mouthpiece Ventilation and Portable Application

Ventilator	Weight (kg, pounds)	Dimensions (height, width, depth, in cm)	Alternating-Current Mode Apnea Duration (s)	Peak Inspiratory Flow Control	Minimum Pressure Alarm (cm H ₂ O)	Minimum Breaths per Minute
Respironics Lifecare PLV100	12.8, 28.2	23 × 31 × 31	15	Flow	2	4
Respironics PLV Continuum	10, 22.2	23 × 31 × 31	15	Flow	3	4
Mallinckrodt Achieva PSO2	14.5, 32	27 × 34 × 40	10	Inspiratory time	3	6
Pulmonetics LTV800	6.5, 14.2	30 × 25 × 8	60 (adjustable)	Inspiratory time	0 (adjustable)	1
Newport HT50	6.8, 15	26 × 27 × 20	30	Inspiratory time	2	3
Uni-Vent Eagle 754	5.9, 13	29 × 22.5 × 11.5	15	Inspiratory time	0 (adjustable)	4

50-mL increments, from 500 mL to 1,000 mL. The low-pressure alarm for each ventilator was set at the minimum pressure level of 2 cm H₂O or 3 cm H₂O, according to the manufacturer's specifications. PIF rates were adjusted per manufacturer's instructions. Once the minimum PIF rate was determined, the ventilator circuit was disconnected at the mouthpiece to ensure low-pressure alarm function in the event of a circuit disconnect. Table 1 summarizes the characteristics of the ventilators that were found to support MPV, including their mandatory ventilator rates, based on maximum apnea duration, minimum low-pressure alarm settings, PIF control mode, ventilator dimensions, and weights. The PIF values in Table 2 are the minimum flow rates that prevented low-pressure alarming.

Results

In the evaluation of currently available pressure-triggered volume-cycled home ventilators included in this study, 6 of the 8 were found to support MPV in the assist-

control mode. The 2 that did not were the Puritan Bennett LP10 and VersaMed iVent 201. In the compilation of ventilator characteristics for those ventilators found to support MPV (see Table 1) there was a wide range of apnea duration among the ventilator brands, which required mandatory machine rates from as low as 1 breath/min to as high as 6 breaths/min. The set machine rate did not affect the PIF rate necessary to prevent low-pressure alarming in an open-breathing-circuit/mouthpiece format. The ventilator weights ranged from 13 pounds to 32 pounds, with corresponding differences in ventilator size.

Importantly, we found that the low pressure alarms on all the ventilators that supported MPV sounded appropriately at the respective manufacturer's minimum low-pressure alarm setting when the MPV circuit was disconnected. The PIF rates and inspiratory times required to prevent low-pressure alarming are given in Table 2. The required flow rates ranged from 18 L/min to 55 L/min. A sufficient PIF to prevent low-pressure alarming was produced by adjusting inspiratory time in relation to the tested tidal volumes with the Achieva, LTV800, HT50, and Uni-Vent.

Table 2. Peak Inspiratory Flow or Inspiratory Time Necessary to Prevent Low-Pressure Alarming at Set Tidal Volumes From 500 mL to 1000 mL, Using the Described Mouthpiece Ventilation Test Circuit*

Set Tidal Volume (mL)	Respironics Lifecare PLV100 (Flow, L/min)	Mallinckrodt Achieva PSO2 (T _I , s)	Pulmonetics LTV800 (T _I , s)	Newport HT50 (T _I , s)	Impact Medical Uni-Vent Eagle 754 (T _I , s)	Respironics PLV Continuum (Flow, L/min)
500	55	1.2	1.7	0.8	0.8	44
550	55	1.4	1.8	0.9	0.9	44
600	55	1.6	2.0	1.0	0.9	44
650	50	1.7	2.2	1.1	1.1	44
700	50	1.8	2.3	1.1	1.1	43
750	35	1.8	2.5	1.2	1.2	43
800	35	1.9	2.7	1.3	1.3	43
850	35	2.1	2.8	1.4	1.4	43
900	35	2.1	3.0	1.5	1.5	43
950	35	2.4	3.2	1.6	1.6	42
1,000	35	2.5	3.3	1.6	1.6	42

*The Puritan Bennett LP10 and the VersaMed iVent 201 ventilators could not be prevented from low-pressure alarming at any of the tested tidal volumes in assist-control mode.

T_I = inspiratory time

As expected, the inspiratory times were decreased in proportion to the decreasing tested tidal volumes, in order to produce sufficient PIF to prevent low-pressure alarming.

Discussion

MPV is indicated when the neuromuscular patient develops either daytime hypercarbia with optimal nocturnal noninvasive ventilation, or daytime dyspnea requiring increased noninvasive ventilatory support.^{9,10} MPV has been successfully used to support portable daytime noninvasive ventilation in neuromuscular patients with chronic respiratory insufficiency. While tracheostomy can provide a secure means of ventilatory support, MPV can provide several benefits over tracheostomy for the respiratory-dependent neuromuscular patient population. By using MPV, the potential for respiratory infection and complications associated with invasive tracheostomy ventilation¹¹⁻¹³ may be avoided. Swallowing problems associated with tracheostomy¹⁴⁻¹⁶ can also be avoided. The neuromuscular patient who has a chronic progressive deterioration in respiratory muscle function is able to receive as much ventilatory support as needed using MPV. In a survey of long-term ventilator users who have been supported by both tracheotomy and noninvasive positive-pressure ventilation with MPV at different times, MPV was preferred for comfort, convenience, speech, and appearance.² Although MPV can be supported using a bi-level pressure generator, the benefit of MPV using pressure-support ventilation is limited by decreasing pulmonary and chest wall compliance associated with progressive respiratory muscle weakness.¹⁷⁻²² A pressure-triggered volume-cycled ventilator can support both hyperinflation and cough augmentation, as well as provide progressive ventilatory support with developing respiratory insufficiency. Despite the availability of this modality, it is not widely used outside of a few centers that specialize in the respiratory care of patients with neuromuscular disease. Part of the reason for this may be that little is known about which available ventilators can support this type of ventilation, and the ventilator settings required. The intent of this article is to provide respiratory therapists with the necessary information to apply MPV as an effective means of portable noninvasive daytime volume ventilatory support.

The table of ventilator specifications (Table 1) is meant to provide a comparison of minimum rate settings according to apnea duration, minimum low-pressure alarm settings, and PIF control modes for the ventilators that supported MPV. Using a minimum assist/control-mode rate allows the MPV user to trigger ventilator breaths as often as needed while receiving a minimum of mandatory ventilator breaths. Ventilator weights and dimensions were included as a comparison of portability for wheelchair

applications, where weight and size may be a consideration in selecting a ventilator.

This study is limited in that we evaluated the ventilators using only one type of commercially available mouthpiece. Other varieties of mouthpieces are available, and their use may result in different PIF rates necessary to silence low-pressure alarms.

Conclusions

We found that open-circuit MPV, using a commercially available breathing circuit format, was supported by 6 of the 8 pressure-triggered volume-cycled home ventilators currently available in the United States. All the ventilators that supported MPV maintained a functional low-pressure alarm in the event of a circuit disconnect, when set at the respective manufacturer's minimum alarm pressure setting.

REFERENCES

- Affeldt JE. Roundtable conference on poliomyelitis equipment. National Foundation for Infantile Paralysis-March of Dimes. White Plains, New York; 1953.
- Bach JR. A comparison of long-term ventilatory support alternatives from the perspective of the patient and caregiver. *Chest* 1993;104(6):1702-1706.
- Bach JR, Alba A, Saporito LR. Intermittent positive pressure ventilation via mouth as an alternative to tracheostomy for 257 ventilator users. *Chest* 1993;103(1):174-182.
- Bach JR, Rajaraman R, Ballanger F, Tzeng AC, Ishikawa Y, Kulesa R, Bansal T. Neuromuscular ventilatory insufficiency: the effect of home mechanical ventilator use v oxygen therapy on pneumonia and hospitalization rates. *Am J Phys Med Rehabil* 1998;77(1):8-19.
- Bach JR. Mechanical insufflation-exsufflation. Comparison of peak expiratory flows with manually assisted and unassisted coughing techniques. *Chest* 1993;104(5):1553-1562.
- Bach JR, Kang SW. Disorders of ventilation: weakness, stiffness and mobilization. *Chest* 2000;117(2):301-303.
- Kang SW, Bach JR. Maximum insufflation capacity. *Chest* 2000;118(1):61-65.
- Kirby NA, Barnerias MJ, Siebens AA. An evaluation of assisted cough in quadriparetic patients. *Arch Phys Med Rehabil* 1966;47(11):705-710.
- Bach JR. Pathophysiology of paralytic restrictive pulmonary syndromes. In: *Pulmonary rehabilitation: the obstructive and paralytic conditions*. Philadelphia: Hanley and Belfus;1996:275-283.
- Curran FJ, Colbert AP. Ventilator management in Duchenne muscular dystrophy and postpoliomyelitis syndrome: twelve years' experience. *Arch Phys Med Rehabil* 1989;70(3):180-185.
- Baydur A, Kanel G. Tracheobronchomalacia and tracheal hemorrhage in patients with Duchenne muscular dystrophy receiving long-term ventilation with uncuffed tracheostomies. *Chest* 2003;123(4):1307-1311.
- Engoren M, Arslanian-Engoren C, Fenn-Buderer N. Hospital and long-term outcome after tracheostomy for respiratory failure. *Chest* 2004;125(1):220-227.
- Sue SD, Susanto I. Long-term complications of artificial airways. *Clin Chest Med* 2003;24(3):457-471.
- Tolep K, Getch CL, Criner GJ. Swallowing disorders in patients with

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- prolonged orotracheal intubation or tracheostomy tubes. *Chest* 1996;109(1):167-172.
15. Bonanno PC. Swallowing dysfunction after tracheostomy. *Ann Surg* 1971;174(1):29-33.
 16. Feldman SA, Deal CW, Urquhart W. Disturbance of swallowing after tracheostomy. *Lancet* 1966;1(7444):954-955.
 17. Papastamelos C, Panitch HB, Allen JL. Chest wall compliance in infants and children with neuromuscular disease. *Am J Respir Crit Care Med* 1996;154(4 Pt 1):1045-1048.
 18. Schmidt-Nowara WW, Altman AR. Atelectasis and neuromuscular respiratory failure. *Chest* 1984;85(6):792-795.
 19. McCool FD, Mayewski RF, Shayne DS, Gibson CJ, Griggs RC, Hyde RW. Intermittent positive pressure breathing in patients with respiratory muscle weakness: alterations in total respiratory system compliance. *Chest* 1986;90(4):546-552.
 20. Estenne M, Heilporn A, Delhez L, Yernault JC, De Troyer A. Chest wall stiffness in patients with chronic respiratory muscle weakness. *Am Rev Respir Dis* 1983;128(6):1002-1007.
 21. Diaz GE, Deoras KS, Allen JL. Chest wall motion before and after mechanical ventilation in children with neuromuscular disease. *Pediatr Pulmonol* 1993;16(1):89-95.
 22. Dean S, Bach JR. The use of noninvasive respiratory muscle aids in the management of patients with progressive neuromuscular disease. *Respir Care Clin N Am* 1996;2(2):223-240.



Iron lungs in poliomyelitis ward
Latter-Day Saints Hospital
Salt Lake City, Utah, 1949
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