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Imposed Work and Oxygen Delivery during Spontaneous Breathing with Adult Disposable Manual Ventilators

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Background: **Manual ventilators (resuscitators) are used primarily to ventilate the lungs of patients lacking spontaneous ventilatory effort. However, in many settings patients are allowed to breathe through the manual ventilator. Although many aspects of manual ventilator function have been studied, very little has been reported on the use of manual ventilators during spontaneous breathing. The purpose of this study was to evaluate inspiratory and expiratory imposed work of breathing and oxygen delivery during spontaneous breathing through disposable manual ventilators.**

Methods: **Simulated spontaneous breathing was established with a two-chambered test lung, with one chamber serving as the test chamber and the other as the driving chamber. Imposed work of breathing was evaluated with decelerating inspiratory flow at a rate of 20 breaths/min at tidal volume (V_T) 0.25 l and peak flow 40 l/min, at V_T 0.5 l and peak flow 80 l/min, and V_T 0.8 l and peak flow 120 l/min. Flow (integrated to volume) and pressure were measured between the manual ventilator and test lung, and inspiratory and expiratory imposed work of breathing were calculated by integration of the volume–pressure curve. Oxygen concentration was measured with an oxygen analyzer placed between the manual ventilator and the test lung at 20 breaths/min, V_T 0.5 l, and flow 45 l/min. An oxygen flow of 15 l/min was added to the device for all evaluations. Two of the manual ventilators had built-in positive end-expiratory pressure valves, and imposed work was evaluated at 10 cmH_2O with these.**

Results: **There were significant differences in imposed work between inspiration and expiration ($P < 0.001$) and among the three levels of ventilatory demand ($P < 0.001$). For each ventilatory demand, there was a significant difference in work between manual ventilator brands for inspiratory work and expiratory work ($P < 0.001$). At a V_T of 0.5 l and peak flow of 80 l/min, the pooled inspiratory imposed work for all manual ventilators was 0.44 ± 0.12 J/l, and the pooled expiratory imposed work was 0.29 ± 0.05 J/l. With 10 cmH_2O positive end-expiratory pressure, the inspiratory imposed work was very high (>1 J/l). Four of the devices were unable to deliver more than 0.85 oxygen concentration at the spontaneous ventilatory pattern evaluated.**

Conclusions: **Adult disposable manual ventilators produce a substantial imposed work of spontaneous breathing, which is increased with the addition of positive end-expiratory pressure. With some manual ventilators, a high oxygen concentration may not be delivered during spontaneous breathing. We recommend that patients not be allowed to spontaneously breathe through disposable manual ventilators. (Key words: Breathing: imposed work. Equipment: manual ventilation devices; resuscitators. Ventilation: emergency; mechanical; oxygen administration; positive end-expiratory pressure.)**

MANY functional aspects of self-inflating bag-valve manual ventilators (commonly called manual resuscitators) have been reported, and this subject has been reviewed in detail elsewhere.[1] Although these devices are most commonly used to ventilate the lungs of apneic patients, they are occasionally used with patients who are spontaneously breathing. Manual ventilators may be used during suctioning procedures or during patient transport, and spontaneous breathing is not unusual in these settings. In fact, it has been the practice of some clinicians to use the manual ventilator as an emergency form of oxygen delivery to spontaneously breathing patients in whom the trachea is intubated.

Disposable manual ventilators have become increasingly popular, and these are available from at least ten manufacturers. Standards for the performance of man-

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ual ventilators have been published by the International Standards Organization (ISO)‖ and the American Society for Testing and Materials (ASTM).# The ASTM and ISO have addressed the issue of valve resistance, and published the standard that back pressure through the valve should be <5 cmH_2O at a flow of 50 l/min. These standards state very little about the performance of manual ventilators during spontaneous breathing but imply that spontaneous breathing should result in the patient breathing oxygen from the device, rather than ambient room air.‖·#

Mills *et al.*[2] evaluated the performance of 13 manual ventilators (9 manufacturers, disposable and nondisposable) during spontaneous ventilation. They found that some devices did not prevent air entrainment from the expiratory port during spontaneous breathing, and thus did not provide adequate oxygen delivery. Inspiratory back-pressure at a constant gas flow of 50 l/min was found excessive with some manual ventilators, but expiratory back-pressure and imposed work of breathing were not evaluated. Hess and Simmons[3] evaluated the resistance to flow through 12 adult manual ventilators (11 manufacturers, disposable and nondisposable). They found significant differences in valve resistance between the devices evaluated, and some were excessive.

The purpose of this study was to evaluate the valve performance of adult disposable ventilators during spontaneous breathing. Specifically, we evaluated the inspiratory and expiratory imposed work of breathing and oxygen delivery using a laboratory model of spontaneous breathing.

Materials and Methods

Manual Ventilators Evaluated

The manual ventilators used in this study were provided by their manufacturers. The brands listed in table 1 were included in all phases of the study.

Imposed Work

Spontaneous breathing was simulated by use of a two-chambered Michigan Instruments Training Test Lung (Grand Rapids, MI). A Puritan-Bennett 7200 ventilator (Carlsbad, CA) was attached to one chamber of the test lung, which served as the driving compartment. The second chamber served as the test compartment and was connected to the driving compartment by a lift bar. The lift bar caused the test chamber to simulate spontaneous inspiration, but it was not fixed to the test chamber to allow expiration to be determined by the resistive properties of the manual ventilation device. The manual ventilator was attached to the test compartment, and ventilation of the driving compartment by the Puritan-Bennett 7200 simulated spontaneous breathing. The experimental set-up (fig. 1) is similar to that used in other studies that have simulated spontaneous breathing in a laboratory setting.[4-6]

Airway pressure was measured with a differential pressure transducer (±100 cmH_2O; MP45-32-871, Validyne, Northridge, CA). Flow was measured with a pneumotachometer (4700, Hans-Rudolf, Kansas City, MO) and differential pressure transducer (±2 cmH_2O; MP45-14-871, Validyne) that was linear over the range used in this study. The pneumotachometer was attached to the test lung, and the pressure port was attached to the manual ventilator. In this configuration, flow resistance through the pneumotachometer was not included in the work calculations. The pressure signal was calibrated at 0 and 20 cmH_2O with a water column, and the flow signal was calibrated at 0 and 60 l/min with a rotameter (Brooks Instrument, Hatfield PA). The flow signal was integrated to volume (7758B, Hewlett-Packard, Palo Alto, CA).

The pressure, flow, and volume signals were captured electronically by a computerized data acquisition system (Codas, Dataq, Akron, OH). Codas was used to

Table 1. Disposable Ventilators Evaluated in This Study

Ambu SPUR, Linthicum, MD; bag and tube style reservoirs
Artec, Indianapolis, IN; bag and tube style reservoirs
Hospitak, Lindenhurst, NY; bag and tube style reservoirs, Bauman PEEP
Intertech 1st Response, Lincolnshire, IL; bag and tube style reservoirs
LSP, Irvine, CA; bag and tube style reservoirs
Mercury Medical, Clearwater, FL; bag and tube style reservoirs
Pulmanex, Carrollton, TX; bag and tube style reservoirs
Puritan Bennett DMR, Lenexa, KS; tube style reservoir
Respironics BagEasy, Monroeville, PA; valves with and without PEEP
Vital Signs Code Blue, Totowa, NJ; tube style reservoir
Vital Signs Code Blue II, Totowa, NJ; tube style reservoir

‖ International Organization for Standardization: International Standard ISO 8382:1988 (E): Resuscitators intended for use with humans. New York, American National Standards Institute, 1988.

American Society for Testing and Materials: Standard specification for performance and safety requirements for resuscitators intended for use with humans: Specification F-920-93. Philadelphia, American Society for Testing and Materials, 1993.

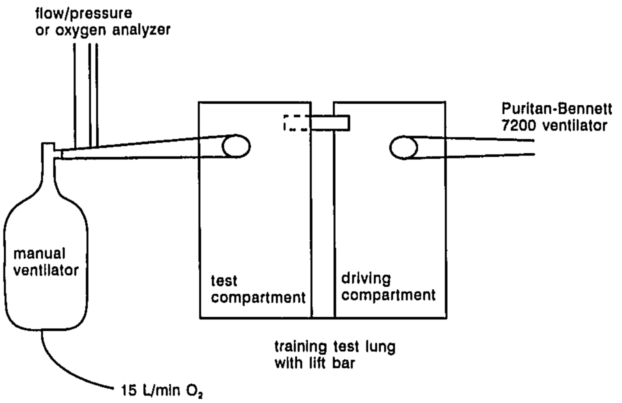


Fig. 1. The experimental set-up used to evaluate imposed work and FD_{O_2} by manual ventilation devices. A Puritan-Bennett 7200 ventilator ventilated one compartment (driving compartment) of a two-chambered test lung. A lift bar simulated spontaneous breathing in the contralateral compartment (test compartment). The dotted part of the bar indicates that it lifts the test compartment to simulate spontaneous breathing; it is not fixed to the test compartment, and thus the recoil of the test compartment depends on the resistive properties of the manual ventilator. Flow and pressure or oxygen concentration was measured between the manual ventilator and the test compartment. An oxygen flow of 15 l/min was added to each manual ventilator.

integrate the volume–pressure loops for inspiratory and expiratory imposed work. The area within the inspiratory and expiratory loops was converted to units of joules and divided by the delivered tidal volume (V_T) to normalize the work in joules per liter.

A rate of 20 breaths/min and a decelerating flow pattern were set on the Puritan-Bennett 7200 for all work evaluations. The following ventilatory patterns were evaluated to simulate low, moderate, and high ventilatory demand: V_T 0.25 l, peak flow 40 l/min; V_T 0.5 l, peak flow 80 l/min; V_T 0.8 l, peak flow 120 l/min. Due to the decelerating flow pattern, this produced an inspiratory time of approximately 0.75 s for each ventilatory demand. Three units of each device were evaluated, and work (joules per liter) was determined for five respiratory cycles for each ventilator. For manual ventilators with a built-in positive end-expiratory pressure (PEEP) valve (Respironics and Hospitak), imposed work was also determined with the addition of 10 cmH_2O PEEP at each of the above ventilatory demands.

Valve Back-pressure at 50 l/min

Back-pressure through the valve at a flow of 50 l/min was determined using the method recommended by the ISO and ASTM. Expiratory back-pressure was evaluated by directing a flow of 50 l/min through the valve in the direction of flow when the patient exhales. Inspiratory back-pressure was evaluated by using a negative flow of 50 l/min through the valve in the direction of flow when the patient inhales. Flow in the expiratory direction was controlled by an air flowmeter (Timeter, Lancaster, PA) connected to the hospital compressed air supply, and flow in the inspiratory direction was controlled by a vacuum regulator (Ohmeda, Madison, WI) attached to the hospital vacuum system. Flow was measured using a calibrated pneumotachometer (Hans-Rudolf 4700, Kansas City, MO) and differential pressure transducer (±2 cmH_2O, MP45-14-817, Validyne). Pressure was measured at the patient connector of the manual ventilator using a calibrated differential pressure transducer (±100 cmH_2O, MP45-32-871, Validyne). Four manual ventilators of each brand were evaluated. Downstream pressure (*i.e.,* distal to exhalation valve) was always atmospheric, and the PEEP devices were not evaluated during this experiment.

Oxygen Delivery

To measure delivered oxygen concentration (FD_{O_2}) during spontaneous breathing, the set-up shown in figure 1 was used. A ventilatory pattern of V_T 0.5 l, rate 20 breaths/min, and decelerating flow of 45 l/min was used. A calibrated oxygen analyzer (Ventronics, Hudson RCI, Temecula, CA) was used to determine FD_{O_2}, and the test lung was ventilated until a stable oxygen concentration was displayed on the oxygen analyzer. The time required to deliver a stable FD_{O_2} was not assessed. For manual ventilators with both tube-style and bag-style reservoirs, this evaluation was performed in both configurations. Three of each manual ventilator were evaluated.

Statistical Analysis

Statistical analysis was performed using spreadsheet (Excel, Microsoft, Redmond, WA) and statistical analysis (SPSS, Chicago, IL) software. Mean and standard deviation were calculated as summary statistics. Differences between groups were determined by analysis of variance, with *post hoc* analysis by Scheffé's method when appropriate. $P < 0.05$ was considered significant.

Results

Imposed Work

The inspiratory and expiratory imposed work levels for all manual ventilators at all three ventilation levels are shown in table 2. There were significant differences between manual ventilators for inspiratory and expiratory work at each level of ventilation ($P < 0.001$ in each case). There were significant interaction effects between brands and direction of flow (inspiratory versus expiratory), and between brands and levels of ventilation. Imposed work increased with increased levels of ventilation ($P < 0.001$), and inspiratory work was greater than expiratory work ($P < 0.001$). There was a significant interaction effect ($P < 0.001$) between level of ventilation and inspiratory versus expiratory work. Inspiratory and expiratory work were similar at the lowest level of ventilation, but became increasingly disparate at higher levels of ventilation (fig. 2).

Work imposed with the two manual ventilators with built-in PEEP valves is shown in table 3. With the Hospitak, PEEP is produced by obstructing the expiratory flow port; doing so causes the device to restrict flow (fig. 3) and makes precise control of PEEP level difficult. For the Respironics, noise produced by the valve made determination of expiratory work impossible (fig. 3). There was a significant increase in inspiratory work with the addition of 10 cmH_2O PEEP to the valve ($P < 0.001$). At the lowest level of ventilation, there was no difference for inspiratory work between the Respironics and Hospitak manual ventilators. However, the inspiratory work was significantly greater for the Hospitak at the higher ventilation levels ($P < 0.05$ by Scheffé's analysis). The expiratory work for the Hospitak was similar with and without the use of PEEP.

Valve Back-pressure at 50 l/min

The inspiratory and expiratory back pressures produced by the valves at a flow of 50 l/min are shown in table 4. There were significant differences ($P < 0.001$) between brands, and between inspiratory and expiratory flows. There was also a significant interaction between brands and direction of flow (inspiratory versus expiratory) ($P < 0.001$).

Oxygen Delivery

The results for FD_{O_2} are shown in table 5. There was a significant difference in FD_{O_2} between manual ventilator brands ($P < 0.001$). All of the brands except the Code Blue, Code Blue II, LSP (tube and bag reservoirs), and Intertech (tube reservoir) produced an $FD_{O_2} > 0.85$ (the ASTM standard). There was a significant difference in FD_{O_2} between tube and bag style reservoirs ($P < 0.001$).

Discussion

We found a high imposed work of breathing through the valves of manual ventilators. The inspiratory imposed work was higher than the expiratory work, and increased with increasing levels of ventilatory demand. The inspiratory imposed work was especially high with the addition of 10 cmH_2O PEEP. Only 7 of the 11 manual ventilators were able to deliver a high FD_{O_2} during spontaneous breathing (>0.85). Although there were differences in FD_{O_2} between the tube and bag style res-

Table 2. Work for the Manual Ventilators Evaluated in This Study at Three Levels of Ventilation

	V_T 0.25 L (peak flow 40 L/min)		V_T 0.50 L (peak flow 80 L/min)		V_T 0.8 L (peak flow 120 L/min)	
Brand	Inspiratory	Expiratory	Inspiratory	Expiratory	Inspiratory	Expiratory
Ambu	0.178 ± 0.011	0.166 ± 0.020	0.418 ± 0.021	0.268 ± 0.018	0.702 ± 0.015	0.381 ± 0.015
Artec	0.236 ± 0.013	0.234 ± 0.021	0.544 ± 0.027	0.317 ± 0.016	0.858 ± 0.038	0.485 ± 0.068
Hospitak	0.205 ± 0.064	0.207 ± 0.025	0.458 ± 0.051	0.324 ± 0.031	0.699 ± 0.030	0.476 ± 0.024
Intertech	0.178 ± 0.042	0.215 ± 0.012	0.390 ± 0.048	0.379 ± 0.034	0.672 ± 0.062	0.478 ± 0.055
LSP	0.162 ± 0.034	0.160 ± 0.030	0.383 ± 0.032	0.278 ± 0.032	0.656 ± 0.054	0.371 ± 0.063
Mercury	0.225 ± 0.012	0.221 ± 0.010	0.447 ± 0.017	0.315 ± 0.023	0.734 ± 0.032	0.412 ± 0.036
Pulmanex	0.518 ± 0.051	0.105 ± 0.031	0.687 ± 0.089	0.260 ± 0.056	0.965 ± 0.097	0.362 ± 0.064
Puritan-Bennett	0.187 ± 0.016	0.112 ± 0.006	0.433 ± 0.013	0.217 ± 0.017	0.746 ± 0.023	0.306 ± 0.023
Respironics	0.205 ± 0.034	0.209 ± 0.022	0.474 ± 0.034	0.263 ± 0.027	0.680 ± 0.040	0.362 ± 0.046
Vital Signs Code Blue	0.090 ± 0.011	0.169 ± 0.014	0.246 ± 0.018	0.280 ± 0.017	0.490 ± 0.016	0.388 ± 0.023
Vital Signs Code Blue II	0.089 ± 0.014	0.132 ± 0.026	0.332 ± 0.067	0.236 ± 0.010	0.837 ± 0.020	0.320 ± 0.020

Values are J/L.

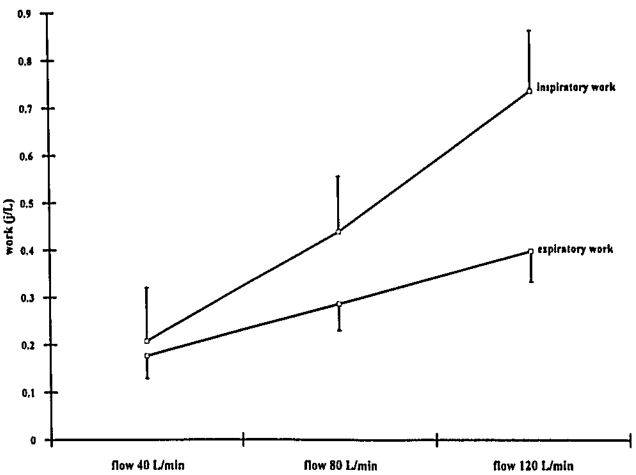


Fig. 2. Inspiratory and expiratory imposed work of breathing through manual disposable ventilators (pooled data) at three levels of ventilatory drive.

ervoirs, this difference was too small to be considered clinically important.

Many evaluations of manual ventilators have been published, including studies of oxygen delivery,[7,8] V_T delivery,[9–12] performance at extremes of environmental conditions,[13] and conformation with the standards of the ASTM.[7,8,13] Most of these evaluations have focused on the performance of these devices during operator-controlled positive-pressure ventilation. This is understandable, because these devices are usually used to provide ventilation to the lungs of apneic patients (*e.g.*, during cardiac arrest). However, they are occasionally used with patients who are spontaneously breathing. It has been the practice of some clinicians to use manual ventilators to provide oxygen (and PEEP) to patients in whom the trachea is intubated and who are breathing spontaneously, particularly during patient transport and during suctioning procedures.

The use of disposable manual ventilators has become increasingly popular in recent years. The models currently available have a variety of valve designs to prevent rebreathing. Most allow the attachment of an accessory PEEP valve or respirometer, and some have a built-in adjustable PEEP valve. The expiratory resistance is determined by the dimensions and geometry of the valve. During spontaneous inhalation, the valve should allow the patient to breathe oxygen from the manual ventilator. To accomplish this, the inspiratory effort must open the valve, decompress the manual ventilator, open the gas intake valve, and draw gas from the attached reservoir. Due to this relatively lengthy gas path with a number of inline obstructions to flow (*i.e.*, valves), it is not surprising that the imposed work of spontaneous inhalation is high and clinically important with these devices.

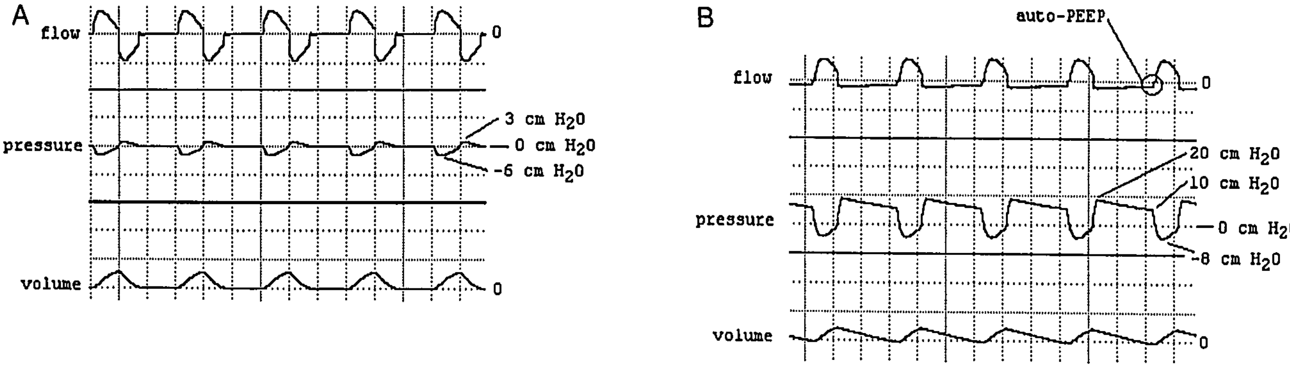
The only other published study that evaluated manual ventilators during spontaneous ventilation was performed by Mills *et al.*[2] They primarily evaluated oxygen delivery during spontaneous ventilation, and they found significant differences in FD_{O_2} between brands. They also found that FD_{O_2} was affected by the level of ventilation, which caused the FD_{O_2} to decrease for some manual ventilators and to increase for others. Not all of the manual ventilators evaluated by Mills *et al.*[2] were disposable, and several of the devices evaluated in that study are no longer commercially available. It is of interest that the Code Blue was one of the devices producing lower FD_{O_2}, which is consistent with our results. Seven of the 11 manual ventilators that we evaluated had a relatively high FD_{O_2} at the ventilation level we used.

All of the manual ventilators but two (Pulmanex and Respironics) met the standard for expiratory back-pressure (<5 cmH_2O at 50 l/min), and all brands except the Pulmanex and Code Blue met the ISO standard for inspiratory back-pressure (<5 cmH_2O at 50 l/min). However, the inspiratory back-pressures for these devices were only slightly greater than the ISO standard (6.0 ± 0.4 cmH_2O for Pulmanex and 6.1 ± 0.5 cmH_2O for Code Blue). Mills *et al.*[2] evaluated inspiratory back-

Table 3. Work for the Manual Ventilators with Built-in PEEP Valves Evaluated in This Study

	V_T 0.25 L (peak flow 40 L/min)		V_T 0.50 L (peak flow 80 L/min)		V_T 0.8 L (peak flow 120 L/min)	
Brand	Inspiratory	Expiratory	Inspiratory	Expiratory	Inspiratory	Expiratory
Hospitak	1.038 ± 0.081	0.146 ± 0.042	1.665 ± 0.070	0.300 ± 0.028	2.062 ± 0.153	0.505 ± 0.053
Respironics	1.000 ± 0.096	Could not be measured	1.346 ± 0.039	Could not be measured	1.661 ± 0.044	Could not be measured

Values are J/L.



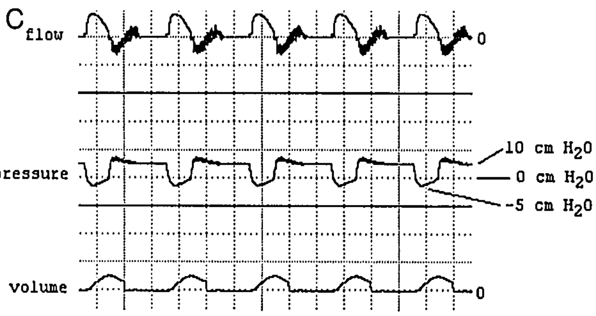


Fig. 3. (*A*) Typical flow (top), pressure (middle), and volume (bottom) waveforms for a manual ventilator (Puritan-Bennett Disposable Manual Resuscitator) without positive end-expiratory pressure (PEEP). Simulated spontaneous breathing is occurring at a tidal volume of 0.5 l and a peak inspiratory flow of 80 l/min. The inspiratory pressure deflection is 6 cmH_2O and the expiratory pressure deflection 3 cmH_2O. (*B*) Typical flow (top), pressure (middle), and volume (bottom) waveforms for the Hospitak manual ventilator with 10 cmH_2O PEEP. Simulated spontaneous breathing is occurring at a tidal volume of 0.5 l and a peak inspiratory flow of 80 l/min. There is a linear decrease in airway pressure and flow during exhalation, which is characteristic of devices that are fixed orifice PEEP devices. PEEP is produced as the result of auto-PEEP generated by the device. Expiratory flow is retarded and does not decrease to zero before the beginning of the next inspiration. Inspiratory pressure deflection is large (18 cmH_2O during inspiration), and expiratory pressure is 20 cmH_2O at the beginning of expiration. (*C*) Typical flow (top), pressure (middle), and volume (bottom) waveforms for the Respironics manual ventilator with 10 cmH_2O PEEP. Simulated spontaneous breathing is occurring at a tidal volume of 0.5 l and a peak inspiratory flow of 80 l/min. Valve noise occurs during exhalation, and inspiratory pressure deflection is large (15 cmH_2O). The valve noise makes flow integration to volume impossible during exhalation.

pressure at a flow of 50 l/min, and found it to be excessive for two devices (Hospitak and Mercury). Hess and Simmons[3] also found higher inspiratory back-pressures with the Hospitak and Mercury. This is in contrast to our results, in which the inspiratory back-pressure was acceptable for both of these devices. The reason for this discrepancy in results is not completely clear, but is presumably related to changes in the construction of the devices used in this study and previous studies. Although the manufacturers were the same, the specific devices used were different for these studies. The devices used in this study were manufactured several years after the devices used in the previous studies.[2,3] We were not particularly surprised by the differences in results, since these are disposable low-cost devices. To our knowledge, the performance reliability of disposable manual ventilators has not been assessed. However, the reliability of another disposable device, the jet nebulizer, was evaluated and found to have large differences in performance between units.[14]

We know of no other studies that evaluated imposed work of spontaneous breathing through manual ventilators. The inspiratory imposed work that we found with these devices was high, particularly with moderate to high ventilatory demands. Ideally, the additional work imposed by respiratory equipment should be zero. At a modest level of ventilatory demand (V_T 0.50 l, flow 80 l/min), the imposed inspiratory work from a manual ventilator could double the work of breathing for some patients (normal inspiratory work of breathing is 0.5 J/l).[15] Prolonged breathing at this additional work load could result in altered breathing patterns and fatigue for some patients. The inspiratory work imposed by the manual ventilators evaluated in this study is approximately 10- to 100-fold greater than that reported by Hirsch *et al.*[6] with many current generation critical care ventilators.

Although generally not as great as the inspiratory imposed work, the expiratory imposed work from the manual ventilators evaluated in this study was also substantial. Although we evaluated expiratory imposed work using a model of spontaneous breathing, the expiratory imposed workloads that we found would also be present with operator-controlled use of the manual ventilator. The expiratory workload is important for several reasons. High expiratory resistance can prolong exhalation, resulting in air-trapping if expiratory time is short. A higher expiratory imposed workload may also be uncomfortable for some patients, particularly during active exhalations.[16] Our lung model only evaluated expiratory imposed work during passive exhalation at relatively low peak expiratory flows, which makes it difficult to compare our data to other studies using critical care ventilators at higher simulated expiratory flows.[16] At low flows the imposed expiratory work with disposable ventilators was similar to that of critical care ventilators at high flows, suggesting that high expiratory flows through these devices (*e.g.*, with a cough) could result in very high expiratory imposed workloads.

The inspiratory imposed work of breathing was excessively high with the addition of 10 cmH_2O PEEP, probably not as a result of the devices *per se* but rather the performance of all manual ventilators when 10 cmH_2O PEEP is added.[17] At this level of PEEP, the patient must produce an airway pressure gradient greater than 10 cmH_2O to maintain inspiratory flow. This situation is unlike current generation critical care ventilators which are PEEP-compensated. With current generation critical care ventilators, inspiratory imposed work with 10 cmH_2O continuous positive airway pressure is greater than with zero continuous positive airway pressure[6] but much lower than that found with manual ventilators in this study. A manual ventilator with PEEP performs like an expiratory positive airway pressure system. In other words, airway pressure must decrease to less than atmospheric pressure before gas flow is established. Although they did not calculate work, Schlobohm *et al.*[18] reported very negative esophageal pressures when expiratory positive airway pressure systems were used in spontaneously breathing critically ill patients. In healthy young athletes, Gherini *et al.*[19] found very high work levels with an expiratory positive airway pressure system. Authors of both of these reports[18,19] recommended against the use of expiratory positive airway pressure systems, and such systems are usually avoided in the care of critically ill patients.

We found clinically important differences in the performance of manual ventilator brands during spontaneous breathing. Design changes are common with disposable devices, and the performance of some of these devices may have changed since we conducted this study (spring 1993). Design changes may also explain why our results differ from those reported in other studies[2,3] that evaluated some aspects of manual ventilator performance during mechanical ventilation.

Based upon the findings of this study, we recommend against the use of disposable manual ventilators during spontaneous breathing, especially if PEEP is provided.

Table 4. Back Pressure through the Valves of the Manual Ventilators Evaluated in This Study at a Flow of 50 L/min

Brand	Inspiratory Back Pressure	Expiratory Back Pressure
Ambu	−4.3 ± 0.1	2.7 ± 0.1
Artec	−5.1 ± 0.3	4.8 ± 0.3
Hospitak	−4.8 ± 0.5	4.6 ± 0.4
Intertech	−3.6 ± 0.3	4.9 ± 0.5
LSP	−4.0 ± 0.4	2.2 ± 0.6
Mercury	−4.0 ± 0.2	4.0 ± 0.1
Pulmanex	−6.0 ± 0.4	5.5 ± 1.6
Puritan-Bennett	−4.7 ± 0.1	2.3 ± 0.1
Respironics	−4.6 ± 0.6	7.9 ± 0.9
Code Blue	−6.1 ± 0.5	2.5 ± 0.2
Code Blue II	−2.4 ± 0.1	3.3 ± 0.2

Values are cm H_2O.

Table 5. FDO_2 of the Manual Ventilators Evaluated in This Study during Spontaneous Breathing

Brand	Reservoir Type	FDO_2
Ambu SPUR	Tube	0.92 ± 0.02
	Bag	0.99 ± 0.01
Artec	Tube	0.93 ± 0.00
	Poppel tube	0.97 ± 0.02
	Bag	0.99 ± 0.01
Hospitak	Tube	0.95 ± 0.05
	Bag	0.99 ± 0.01
Intertech	Tube	0.78 ± 0.13
	Bag	0.93 ± 0.06
LSP	Tube	0.81 ± 0.09
	Bag	0.75 ± 0.16
Mercury	Tube	0.95 ± 0.04
	Bag	0.98 ± 0.02
Pulmanex	40-inch tube	0.99 ± 0.00
	60-inch tube	0.99 ± 0.00
	Bag	0.97 ± 0.00
Puritan-Bennett	Tube	0.95 ± 0.02
Respironics	Bag	1.00 ± 0.00
Code Blue	Tube	0.29 ± 0.08
Code Blue II	Tube	0.45 ± 0.05

All of the disposable manual ventilators evaluated produced a substantial inspiratory imposed work of breathing that was markedly increased with some the addition of PEEP. With some brands, a high FD_{O_2} may not be provided during spontaneous breathing.

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