Demand and Continuous Flow Intermittent Mandatory Ventilation Systems*

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A mechanical lung was used to evaluate the pressure and flow characteristics of four demand and two continuous flow intermittent mandatory ventilation (IMV) systems. The amount of negative pressure required to initiate inspiratory flow and peak expiratory resistance were measured. The inspiratory pressure required to initiate flow in the demand mode was also compared to pressures generated in the assist mode. In addition, the peak expiratory resistance was measured with four commercially available exhalation valves. Results showed that the ventilator manometer measuring internal machine pressures significantly underestimated the amount of negative pressure required to open the demand valve (p<0.01). There are major differences in the flow and pressure characteristics among demand and continuous flow IMV systems. Systems that impose high inspiratory elastic threshold loads and expiratory flow resistive loads may have a deleterious effect on the mechanics of breathing, and thereby limit weaning success and eventually impair the recovery of certain patients in respiratory failure. The basic methodology, especially the simple technique of inserting an aneroid manometer in line next to a patient’s ET tube, for measuring proximal negative inspiratory force (NIF test) can be easily applied to any and all ventilators at any practitioner’s individual institution.

Intermittent mandatory ventilation (IMV) has been employed in the management of respiratory failure for over a decade.1,4 Originally, IMV was often used as a new method to facilitate weaning from mechanical ventilation.1,5 However, it has been the clinical experience of others,7,8 as well as our own, that this modality may actually hinder the weaning process of certain patients. The issue remains controversial because the superiority of IMV over other forms of mechanical ventilatory support has not been scientifically established,9 and therefore, this study was done.

Over the years, two different methods for delivery of IMV have evolved: one system operates on the principle of “demand” flow and the other system on “continuous” flow. Demand systems utilize a one-way valve which opens when sufficient negative pressure is generated during the patient’s spontaneous inspiratory efforts occurring between ventilator volume-cycled breaths. This “demand valve” resembles the pressurized valve of a scuba lung and theoretically delivers just enough gas flow to meet inspiratory demands. On the other hand, continuous flow systems do not utilize a pressurized valve; rather, a constant flow passes the airway allowing the patient to inhale oxygen-enriched humidified gas between ventilator-delivered breaths. Both demand and continuous flow methods have become popular and a wide variety of equipment styles and manufacturers have evolved.

The purpose of this study was to evaluate the mechanical properties of a number of commercially available demand and continuous flow IMV systems. A mechanical lung model was used to allow for a standardized reproducible system and to eliminate uncontrolled patient variables. We found that there are significant differences between demand and continuous flow IMV systems in regard to the amount of negative pressure required to initiate inspiratory flow and the flow resistance encountered during exhalation. We suggest that the amount of ventilatory work required to overcome the inspiratory elastic threshold loads and expiratory resistive loads during mechanical ventilation with certain systems may negatively influence the outcome of attempts to wean certain patients recovering from respiratory failure.

METHODS

IMV Systems

Twenty-five ventilators produced by five manufacturers were evaluated (N = 5 in each group). The demand IMV ventilators evaluated were the Servo 900 B (Siemens-Elma A. B. Solna, Sweden), the Bear I (Bear Medical Systems, Inc, Riverside, CA), the...
MA-1 equipped with a model 9200 demand valve (Puritan-Bennett Corp, Kansas City, MO), and the 225 SIMV (Monaghan, Division of Sandoz-Wander, Littleton, CO). The 225 SIMV was included in this group because the mechanism of cycling closely resembles that of a demand valve. The continuous flow ventilators included the Emerson IMV (JH Emerson C., Cambridge, MA) and the same five MA-1 ventilators with the demand valve replaced by an "H" IMV manifold (model 1654, Hudson Oxygen Therapy Sales Co, Temecula, CA). The Emerson IMV and MA-1 were operated at a continuous flow of 20 L/minute.

All ventilators were equipped with a model 3792 mainline bacterial filter and a Cascade 1 humidifier (Puritan-Bennett Corp., Kansas City, MO). The humidifier water reservoir was filled but was not heated to minimize variation in flow measurements resulting from variation in gas temperature. The Bear I, MA-1, and 225 SIMV ventilators were equipped with a standard disposable breathing circuit (model 1624, Hudson Oxygen Therapy Sales, Temecula, CA).

The Emerson IMV and Servo 900 B required utilization on non-disposable circuits supplied by the manufacturer. All IMV systems were carefully operated according to manufacturer's recommendations.

**Mechanical Evaluation of IMV Systems**

A mechanical test lung (Dixie USA Inc, Houston) was utilized to allow all equipment to be tested under rigidly controlled and reproducible conditions (Fig 1). A reciprocating camshaft drive was connected to the test lung, and the system (Fig 1) was adjusted to deliver a sine wave ventilatory pattern frequently encountered during spontaneous breathing on IMV. The lung was cycled at a fixed rate of 24 cycles per minute with a constant inspired volume of 300 ml and a compliance of .075 L/cm H2O. A pneumotachometer (Fleisch No. 1) and a pressure transducer (model MP45, Validyne) were placed in line between the 9 mm endotracheal tube of the test lung and the 15 mm tubing connection (point P1) of the IMV system.

![Diagram](image)

**Figure 1.** Mechanical lung employed to evaluate "spontaneous" breaths during demand and continuous flow IMV. Flows and pressures encountered during inspiration and expiration were displayed on a multichannel recorder. The maximal negative deflection observed on the ventilator manometer during inspiration was noted.

![Graph](image)

**Figure 2.** The amount of negative pressure generated at the endotracheal tube prior to the initiation of inspiratory flow is presented and compared to the maximal negative deflection observed on the ventilator manometer during inspiration. Demand IMV ventilator manometers significantly underestimated the actual airway pressures. The Bear I manometer was as accurate as the continuous flow systems when in the "airway" setting (dashed bar). The pressure required to generate flow was highest with MA-1 and Servo demand systems.
Demand

Instantaneous pressures and flows obtained during inspiration and expiration were displayed on a multichannel chart recorder. The data were obtained from five cycles and then expressed as the mean.

The following measurements were made: at the beginning of the inspiratory phase, the maximal negative pressure generated at P1, just prior to the initiation of flow was noted (Fig 1). This measurement was compared to the maximal negative deflection that was displayed on the ventilator manometer. The maximal expiratory flow and corresponding pressure were also observed. Since the pressure at the expiratory port of the ventilator (point Pp) was atmospheric, the maximal resistance (R max) across the IMV circuit during maximal expiratory flow (V max) can be calculated by dividing the pressure recorded at point Pp by V max:

\[ R_{\text{max}} = \frac{P_{\text{max}} (\text{at point } P_p)}{V_{\text{max}}} \]

**RESULTS**

The amount of negative pressure required to initiate inspiratory flow (point P1) is shown in Figure 2. The transducer pressure measured at the artificial airway (endotracheal tube) was greater than the pressure displayed on the ventilator manometer of demand IMV systems (p<0.01). In contrast, continuous flow ventilator manometers uniformly showed pressures which were identical to the transducer pressures. The discrepancy between transducer and ventilator manometer pressures with demand IMV occurs because ventilator manometers generally reflect internal machine pressures rather than pressures generated at the airway. Therefore, any device (ie, a slow responding demand valve) placed between the endotracheal tube and the machine manometer increases resistance and causes a further drop in pressure across the system during an inspiratory effort. Consequently, the ventilator would then record a lower pressure than that which would be generated at the endotracheal tube during inspiration. As a case in point, Bear I ventilation manometers significantly underestimated the transducer pressure recorded at the endotracheal tube when adjusted to the optional "machine" pressure mode, but accurately reflected the pressure when placed in the "airway" pressure mode (Fig 2).

Although the transducer inspiratory pressures tended to be lower with continuous flow than with demand systems as a group (Fig 2), the differences were not significant. Furthermore, the pressures encountered with the MA-I ventilators equipped with demand valves were greater than the pressures generated with the same ventilators set up to deliver continuous flow. These data suggest that the increased pressure requirements were due to the demand valve attachment rather than a mechanical property of the MA-I ventilator.

To determine if a greater inspiratory pressure might be required to initiate flow with demand IMV than with assisted ventilation, the measurement of transducer inspiratory pressures as described in methods was repeated after each of the five MA-I, Servo 900 B, and Bear I ventilators was switched from "demand" IMV to the "assist" mode (Fig 3). The results showed that a greater negative pressure was required to initiate flow with demand IMV as compared to the assist mode (p<0.01).

Maximal expiratory resistance results are shown in Figure 4. Resistance was greater with demand IMV systems as a group (p<0.01) with values as high as 8 to 9 cm H2O/L-sec seen with the 225 SIMV and Servo 900 B ventilators, respectively. The source of this resistance is probably due to either the intrinsic resistance of the exhalation valve structure itself, or the inefficiency of the ventilator in totally releasing pressure from the mushroom cap of the valve (MA-I, 225 IMV, Bear I) or the exhalation valve seat (Servo 900 B). In order to evaluate the resistance of a number of commercially available exhalation valves, the pressure drop was recorded as a flow of 30 L/minute was passed through five exhalation valves obtained from each of the following manufacturers: model P-007576, Air Life Inc, Subsidiary of American Hospital Supply Corp, (Montclair, CA); model 5844, Becton Dickinson and Co., (Lincoln,
is in the demand IMV mode as compared to assisted ventilation. This inspiratory pressure requirement constitutes an elastic threshold load. In general, loads increase the work of breathing.\textsuperscript{10} Gibney and co-workers\textsuperscript{11} have recently shown that greater inspiratory work was encountered when normal subjects breathed through demand IMV ventilators as opposed to continuous flow. Our results and the results of Gibney and co-workers\textsuperscript{11} suggest that increased inspiratory work is encountered with demand IMV and is due to the elastic threshold load imposed by the demand valve.

Resistance to expiratory flow was also evaluated in this study. Results showed that expiratory resistance was greater with demand IMV than with the continuous flow group and could be modified by the exhalation valve employed. It has also been established that expiratory flow resistive loads can increase the work of breathing.\textsuperscript{12}

The effect of added loads on the mechanics of breathing has been evaluated in normal subjects and in patients with stable lung disease.\textsuperscript{13} However, the effect of loaded breathing on respiratory mechanics in patients with acute respiratory failure has not been investigated in depth. For example, the effect of an expiratory threshold resistor (PEEP) on hemodynamics and gas exchange in respiratory failure has been extensively studied but little is known about the potential effect of PEEP on the respiratory muscles.\textsuperscript{14}

Perhaps the elastic and flow resistive loads suggested by this study have no effect on patients supported by mechanical ventilation. Our clinical experience suggests that most patients are easily managed when either IMV or assist-control mode are employed, and it makes little difference which of the numerous commercially-available ventilators is used. Extubation is successfully accomplished in most cases within hours or a few days. We suspect that the majority of these patients have normal or only minimally and/or transiently impaired respiratory muscle function, and the range of respiratory loads encountered in this study are easily tolerated.

A minority of patients are difficult to wean from mechanical ventilation due to either severe respiratory muscle weakness or fatigue, and it is generally difficult to clinically distinguish between the two entities. It is proposed that patients with respiratory muscle fatigue would do poorly when respiratory loads encountered during mechanical ventilation result in an increased work of breathing. The role of mechanical support in this setting should be to allow recovery of fatigued muscles by minimizing respiratory work.

There is some evidence to suggest that “loaded” breathing may strengthen weak respiratory muscles.\textsuperscript{15} However, the application of inspiratory resistive training for ten minutes, two or four times per day in the management of outpatients with stable COPD, may be
seem quite different than the continuous application of both inspiratory and expiratory loads during the mechanical support of patients in acute respiratory failure.

Perhaps "loaded" breathing during mechanical ventilation may weaken or fatigue the respiratory muscles of patients with minimal reserve. We recently simultaneously recorded pressure and flow at the tracheostomy tube of a COPD patient who was supported by demand IMV and had repeatedly failed attempts to wean from a Servo 900 B ventilator. Recordings obtained during quiet and labored breathing on IMV are shown in Figure 7. It can be seen that the maximal negative inspiratory pressure encountered during quiet breathing on the Servo 900 B (−6 cm H₂O) was comparable to that which was observed when the lung model was used (Fig 2). A even greater negative inspiratory pressure (−10 cm H₂O) was required during labored breathing. At the time the recordings were made, the patient's negative inspiratory force (NIF) measured by the transducer was only −12 cm H₂O. Therefore, it was necessary for the patient to generate 50 percent of her maximal negative inspiratory pressure during each tidal breath and this increased to 83 percent during labored breathing. Roussos and co-workers7 demonstrated that fatigue occurred when normal subjects attempted to sustain a mouth pressure that was greater than 60 percent of their initial maximal inspiratory pressure (NIF). Based on this study in normal subjects, one would predict that our patient would develop respiratory muscle fatigue (if it were not already present) as a result of the inspiratory load encountered with labored breathing on demand IMV. Perhaps patients with lung disease have a fatigue threshold which may be below 60 percent of their NIF. This study also suggests that, even if the pressure threshold for fatigue of a given patient was known, one would not be aware of the fact that fatigue was eminent unless the ventilator pressure gauge reflected true airway rather than internal machine pressure.

The expiratory pressures and flows seen when the COPD patient was supported by demand IMV is shown in Figure 7. The peak expiratory resistance during quiet breathing was 17 cm H₂O/L-sec (10 H₂O cm./L-sec) and increased to 24 cm H₂O/L-sec (16 cm./L-sec) when breathing became labored.

It has been suggested that patients with COPD may benefit from the finely controlled extrathoracic flow resistive loads imposed by expiratory glottic narrowing13 and/or pursed lip breathing.14 It has been speculated that resulting back-pressure may prevent collapse of airways within the lung.15-18 Since the entire upper airway (including the glottis and lips) is bypassed with a tracheostomy or endotracheal tube, fine control of expiratory flow cannot occur.

One of the goals of weaning should be to remove the rather fixed resistance imposed by the endotracheal or tracheostomy tube in order to allow the glottis and lips to maintain a tight physiologic regulation of expiratory airflow. In fact, it has been our experience and the observation of others18 that the endotracheal tube itself may impose an excessive resistance. This is most likely to occur when COPD patients are allowed to breathe unassisted through an endotracheal tube of 7 mm or less and when "T" piece weaning trials are extended past 30 to 60 minutes.19

We have observed that marginal weaning candidates, particularly these with COPD, tend to do poorly when expiratory flow resistive loads are encountered with IMV (or assist-control ventilation). A "qualitative" assessment of that load can be appreciated by observing the rate of fall in expiratory pressure as reflected by the ventilator manometer. Thus, a "retarded" fall in expiratory pressure indicates a prolonged expiratory flow. If flow is slowed to the extent that FRC is not reached prior to the initiation of the next breath, end-expiratory lung volume will increase and end-expiratory pressure remains positive. The net result is "auto-PEEP" and the deleterious effects have been described.20 Our clinical experience suggests that this potential complication of mechanical ventilation can be avoided if the low resistance equipment identified in this study is employed.

Finally, since the completion of this study, we have used "Neff's NIF" to clinically evaluate inspiratory elastic threshold loads in marginal weaning candidates supported by mechanical ventilation. The aneroid manometer used to measure NIF is placed in line

![Diagram](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21466/ on 06/26/2017)
between the endotracheal or tracheostomy tube and the ventilator adaptor. If the maximal negative pressure recorded at the beginning of inspiration is in excess of 4 cm H₂O or is greater than 30 percent of the standard occluded NIF, ventilation equipment and/or modes are changed until inspiratory pressures fall below these limits.

We conclude that there are major differences among the mechanical properties of mechanical ventilators, breathing modes, and ventilator accessory equipment. A variety of elastic and flow resistive loads are likely to be encountered during mechanical ventilation. Future studies should be designed to evaluate the potential effect of these loads on the wide variety of patients that develop respiratory failure.

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