Accuracy of the Oxygen Cylinder Duration Calculator of the LTV-1000 Portable Ventilator

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BACKGROUND: Resource planning is essential for successful transport of the mechanically ventilated patient. Mechanically ventilated patients require adequate oxygen supplies to ensure transport is completed without incident. The LTV-1000 portable ventilator utilizes a program to calculate oxygen cylinder duration, based on cylinder size, fraction of inspired oxygen (F_{IO_2}), and current minute ventilation. We evaluated the accuracy of the cylinder-duration algorithm in a laboratory setting. METHODS: The LTV-1000 was attached to a test lung. Lung compliance was set at 0.04 L/cm H_2O, and airway resistance was 5.0 cm H_2O/L/s. We tested 7 different combinations of ventilator settings a minimum of 2 times each. With each setting, minute ventilation was kept at 10 L/min. Breath type, positive end-expiratory pressure, and F_{IO_2} were varied to evaluate the accuracy of the algorithm across a range of clinical scenarios. The cylinder-duration calculation from the ventilator program and manual calculation was determined at each setting and compared to the actual cylinder duration. RESULTS: The ventilator algorithm and the manual calculation underestimated the actual cylinder duration by 12 ± 3% with each test. The range of differences between calculated and actual cylinder duration was 2–26 min across the 7 conditions. CONCLUSION: Actual cylinder duration averaged 12% longer than the cylinder duration estimated by the algorithm of the LTV-1000. One explanation is that the E cylinders may contain more liters of oxygen than indicated by the sticker on the side of the tank. Additionally, the bias flow during expiration is affected by inspiratory-expiratory ratio and respiratory rate. Clinicians should be aware of these differences when planning for patient transport. *Key words: transport, portable ventilator, oxygen utilization.* [Respir Care 2009;54(9):1183–1186. © 2009 Daedalus Enterprises]

Introduction

Interhospital and intrahospital transport of mechanically ventilated patients is a common event in modern medicine. The use of advanced radiologic interventional and diagnostic techniques has increased the frequency of intrahospital transport of critically ill, mechanically ventilated patients.[1-4] Resource planning is essential to ensure that transport proceeds smoothly and safely. The goal of any patient transport is to obtain the desired diagnostic information or perform the required procedure while minimizing risk and avoiding mishaps.[4-6]

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Planning for transport of the mechanically ventilated patient requires experience, time, and careful determination of necessary resources. Adequate oxygen supplies are essential for the safe transport of critically ill patients. Respiratory therapists commonly determine the required oxygen resources via manual calculation. Manual calculation of the duration of an E cylinder (in minutes) for a

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Table 1. Ventilator Setting Combinations During the Study

Test	Test Breath Type	Respiratory Rate (breaths/min)	Tidal Volume (L)	PEEP (cm H_2O)	F_{IO_2}
1	Volume	20	0.5	20	1.0
2	Volume	20	0.5	0	1.0
3	Volume	20	0.5	0	0.6
4	Volume	20	0.5	0	0.4
5	Pressure*	20	0.5	0	1.0
6	Volume	10† (20 total)	0.5	0	1.0
7	Volume	10† (20 total)	0.5	0	1.0

* Peak pressure setting was 13 cm H_2O.
† Simulated patient-triggering of 20 breaths/minute.
PEEP = positive end-expiratory pressure

given ventilator setting is accomplished by using the following formula:[1]

$$(\text{Cylinder pressure in psig} - 35 \times 0.32)/\{(F_{IO_2} - 0.21)/0.79 \times [\dot{V}_E + (\text{bias flow} \times \text{expiratory fraction})]\}$$

where F_{IO_2} is fraction of inspired oxygen, $\dot{V}_E$ is minute volume (L/min), and expiratory fraction is expiratory time divided by total breath cycle time.

The LTV-1000 portable ventilator (Pulmonetic Systems, Minneapolis, Minnesota) utilizes a program to calculate oxygen cylinder duration. We evaluated the accuracy of this algorithm in a laboratory setting.

Methods

We utilized 2 LTV-1000 portable ventilators to test the accuracy of the oxygen cylinder duration algorithm. Each test was done with a full E-type oxygen cylinder, using the same calibrated regulator (Amvex, Ontario, Canada). Beginning cylinder pressure range was 2,000–2,100 psig (mean 2,078 ± 41 psig). We evaluated 7 combinations of ventilator settings to assess the effect of mode, positive end-expiratory pressure (PEEP), and fraction of inspired oxygen (F_{IO_2}) combinations on cylinder duration. In each test the respiratory rate was 20 breaths/min and the inspiratory time was 1 second. In volume-control mode the tidal volume (V_T) was set at 0.5 L. In pressure-control mode the peak pressure setting was 13 cm H_2O to deliver approximately 0.5 L. Assist/control mode was used for all tests. The cylinder-duration test was performed at each combination of ventilator settings a minimum of 2 times. Table 1 describes the 7 different combinations of settings. A ventilator was chosen randomly for the first test and was alternated with the other ventilator for each subsequent test. The difference in performance of the 2 ventilators was $< 10\%$ on the same settings, so the values were averaged for analysis.

For each test, the ventilator was attached to one chamber of a dual-chamber training and test Lung (Michigan Instruments, Grand Rapids, Michigan). Lung compliance was set at 0.04 L/cm H_2O, and resistance was 5.0 cm H_2O/L/s. We used a differential pneumotachometer (Hans Rudolph, Kansas City, Missouri) to verify the V_T and an oxygen analyzer (MiniOX I, MSA Catalyst Research, Mars, Pennsylvania) to verify the F_{IO_2}. The desired ventilator parameters were set. The oxygen cylinder duration calculator program was accessed by entering the extended features menu.[7] The program asks for cylinder size in liters. We used 697 L to indicate a full E cylinder. The program also requires tank pressure to be entered, in psig. After entering this information into the program, the "calculate" button is pressed and the calculated cylinder duration in minutes is displayed. The calculation was made at end-exhalation with each test, for consistency. This algorithm utilizes the current $\dot{V}_E$ measured by the ventilator and knowledge of the continuous flow during expiratory time (10 L/min × expiratory fraction time). We found that the ventilator requires 2–3 breaths to stabilize and provide a consistent calculation reading. The test was considered finished when the "low oxygen pressure" alarm was activated by the ventilator. This alarm threshold was set by the manufacturer at 35 psig.

Two additional tests were done to evaluate the effects of changing $\dot{V}_E$ by simulating patient triggering (see Table 1, tests 6 and 7). A lift bar was placed between the test lung chambers, such that a driving ventilator simulated spontaneous breathing. For both tests the respiratory rate for the test ventilator was set at 10 breaths/min. The respiratory rate for the ventilator simulating patient effort (driving ventilator) was set at 20 breaths/min. One test was done with the driving ventilator assisting throughout the test. The cylinder-duration calculation was made while the driving lung assisted ventilation. The final test was accomplished with the driving ventilator initiating triggered breaths 15 min after the initial calculation was made. This test was done to determine the ability of the algorithm to account for changes in $\dot{V}_E$ created by patient effort. Cylinder duration was recalculated by entering the current psig into the program at that time.

Table 2. Comparison of the Expected Duration of Manual and Ventilator-Calculated Values to Actual Cylinder Duration

Test	Manual Calculation	Ventilator Calculation (mean ± SD min)	Actual Duration (mean ± SD min)	*P*
1	38.6	38.0 ± 1.4	43.0 ± 1.4*	.07
2	38.3	37.7 ± 1.0	43.0 ± 2.1*	.01
3	80.5	78.0 ± 0.0	91.0 ± 0.5†	.005
4	165.0	162.0 ± 1.4	188.5 ± 2.1*	.005
5	39.5	39.3 ± 0.6	41.8 ± 2.3*	.16
6	39.1	38.5 ± 0.7	44.5 ± 0.7*	.01
7	28.1	28.0 ± 0.0	32.5 ± 0.7*	.01

* Peak pressure setting was 13 cm H_2O.

† Simulated patient-triggering of 20 breaths/minute.

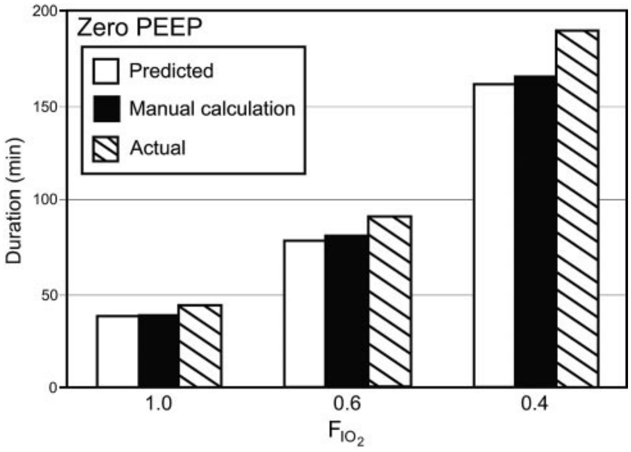

Fig. 1. Effect of varying the fraction of inspired oxygen F_{IO_2}) while maintaining positive end-expiratory pressure (PEEP) constant on calculated and actual cylinder duration.

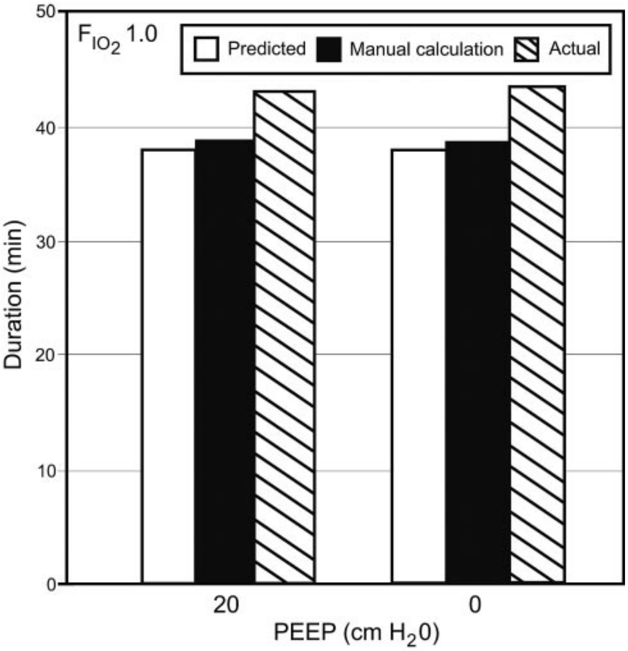

Fig. 2. Effect of positive end-expiratory pressure (PEEP) on cylinder duration.

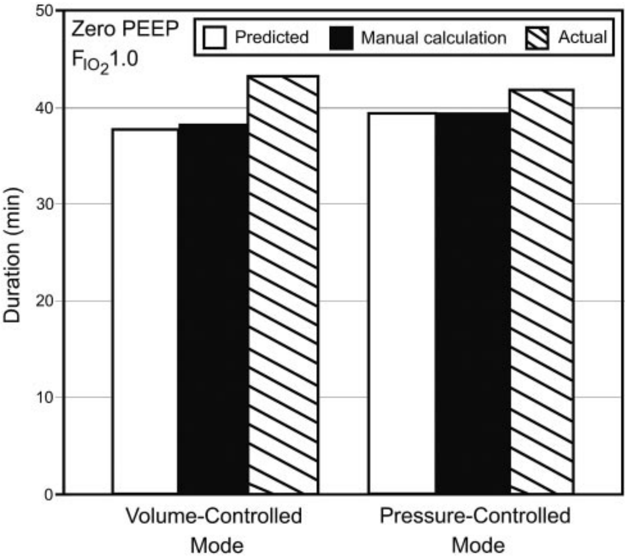

Fig. 3. Effect of breath type (volume versus pressure) at a given positive end-expiratory pressure (PEEP), fraction of inspired oxygen F_{IO_2}), and tidal volume on actual and calculated cylinder duration.

Data are represented as mean ± SD. Comparisons of actual to calculated cylinder-duration data were compared using Student's *t* test. A $P < .05$ was considered significant.

Results

The results for all 7 tests are shown in Table 2. For each test the ventilator's algorithm underestimated actual cylinder duration by 12.0 ± 3.0%. Differences in the calculated and actual cylinder duration were affected by changes in F_{IO_2}. Calculated cylinder duration differed from the actual duration by an average of 5.0 min at an F_{IO_2} of 1.0, by 6.0 min at an F_{IO_2} of 0.6, and by 26.0 min at an F_{IO_2} of 0.40. Figure 1 shows the effect of varying F_{IO_2} while maintaining PEEP constant on calculated and actual cylinder duration. The addition of PEEP had no effect on the calculated or actual cylinder duration. Figure 2 shows the effect PEEP has on cylinder duration. Figure 3 demonstrates the effect of breath type (volume vs pressure) at the same PEEP, F_{IO_2}, and V_T on actual and calculated cylinder duration. For each combination of ventilator settings we also manually calculated the predicted cylinder duration (see Table 2). The difference between manually calculated duration and ventilator-calculated duration was 3% or less with each ventilator setting combination.

We assessed the effect of spontaneous breathing on cylinder calculated and actual duration in tests 6 and 7 (see Table 1). The addition of 20 spontaneous breaths/min before the calculation was made did not affect the accuracy of the algorithm, as compared to all mandatory breaths. For test 7 the calculated cylinder duration was 45 min. After 15 min the driving ventilator began initiating at 20 spontaneous breaths/

min. The recalculated duration was 28 min. Compared to the initial 45 min, this was 2 min less than expected.

Discussion

We found the LTV-1000 ventilator algorithm predicted oxygen cylinder duration in agreement with a standard manual calculation. Both calculated methods, however, underestimated the actual cylinder duration. After testing different combinations of ventilator settings, we found the only parameter that affected the difference between predicted and actual cylinder duration was change in F_{IO_2}. Duration of cylinder operation in our trial on an F_{IO_2} of 1.0 and a $\dot{V}_E$ of 10 L/min was 11 min, or 26% longer than the results reported by Chipman et al.[8]

The LTV-1000 provides 10 L/min bias flow during the expiratory time to facilitate stable PEEP and flow-triggering. This additional gas usage was accounted for in our manual calculations. The additional gas consumption created by the expiratory bias flow is predominately affected by the respiratory rate, inspiratory-expiratory ratio, and the resulting expiratory time. The ability to turn off this feature would increase both the calculated and actual cylinder duration. An important issue in this study is that $\dot{V}_E$ needs to remain stable for the ventilator calculations to be accurate. If the $\dot{V}_E$ changes after the calculation, the initial duration is rendered inaccurate and the operator must reenter the variables into the algorithm.

Another important issue is the variables that can be selected for input into the LTV-1000's algorithm. The LTV-1000 program asks for the size of the cylinder being used, in liters. The default value in the program is 622 L. Chipman et al[8] used 660 L as the cylinder volume in their studies. In our study each of the cylinders used included a label suggesting that cylinder volume was 697 L. Using the reported liter volume of the cylinder is important when inputting the variables into the algorithm and performing the manual calculation. For the algorithm calculations, the LTV-1000 derives the cylinder coefficient (tank factor) from the reported liter volume of the cylinder divided by the tank pressure. With the cylinders we used, the calculation was 697/2,000 or 697/2,100, which yields tank factors of 0.35 or 0.33, respectively, compared to 0.28, which is commonly described as the E cylinder factor. Using the correct tank factor is important to accurately calculating the cylinder duration manually. Clearly, if the cylinder duration is greater than expected, there are few complications. However, if cylinder duration is shorter than expected, catastrophe could result.

Oxygen cylinders are inspected and pressure tested every 10 years, as indicated by a star on the shoulder of the cylinder. The numbers after DOT indicate the normal filling pressure of 2,015 psi. The + indicates the cylinder can be safely filled to 110% of the service pressure.[9] If the nominal volume is 697 L and the cylinder can be filled to a value 10% greater, the result is 767 L. The inconsistency of cylinder filling volumes and the gauge accuracy of 4% of full scale[10] may explain why actual E cylinder duration was greater than predicted.

Since the actual duration of an E-type oxygen cylinder is approximately 12% longer than was calculated by the ventilator or manually, the clinician has extra time that could be valuable when delays occur during patient transport. This could provide an extra 5.0–26.0 min of oxygen, depending on the F_{IO_2}. After the oxygen supply is depleted, we found that the LTV-1000 continues to deliver the set V_T but with an F_{IO_2} of 0.21.

Although we used a new cylinder regulator, a limiting factor was the inability to obtain exact pressure readings, since the gauge markings were in 100-psi increments. We used 2 different ventilators to avoid the problem of relying on the performance of a single ventilator, but cannot claim all ventilators operate accordingly. Finally, we did not measure the volume of the individual cylinders, so variability in the actual volume of individual cylinders could not be accounted for.

Conclusions

The LTV-1000 portable ventilator cylinder-duration algorithm underestimates the actual cylinder duration. The accuracy of the ventilator algorithm works on the assumption that the $\dot{V}_E$ is stable. If the $\dot{V}_E$ either increases or decreases after the calculation is made, the cylinder duration displayed by the ventilator will be inaccurate. Accessing the algorithm and recalculating based on the new settings is required to account for these changes, so the calculation for the remaining contents of the cylinder will be accurate. The clinician should be aware of these differences during patient transport.

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