Evaluation of the Ventilator-User Interface of 2 New Advanced Compact Transport Ventilators

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BACKGROUND: Mechanical ventilation during patient transport frequently utilizes compact portable pneumatic ventilators that have limited ventilator-settings options. New advanced transport ventilators should yield quality improvements, but their user-friendliness needs to be tested. OBJECTIVE: To evaluate the ventilator-user interface of 2 new transport ventilators. METHODS: This was a 2-center descriptive study in which the ventilator-user interfaces of the Oxylog 3000 and Elisée 250 were compared by 20 French senior emergency physicians who were initially unfamiliar with these ventilators. Each physician carried out 15 tasks with each ventilator and then assigned each ventilator a satisfaction score. RESULTS: With the Elisée 250 the task success rate was significantly higher (85.6% vs 66.6% with the Oxylog 3000, p < 0.0001), and the total number of errors was lower (46 vs 113). The main errors were related to inspiratory flow settings with the Oxylog 3000 (31 errors), inspiratory-expiratory ratio settings with the Elisée 250 (11 errors), ventilation mode choice with the Oxylog 3000 (17 errors), trigger sensitivity setting with the Elisée 250 (16 errors) and Oxylog 3000 (11 errors), and alarm range setting with the Oxylog 3000 (10 errors). The mean satisfaction score was significantly better with the Elisée 250 (81% ± 7, range 64–92%) than with the Oxylog 3000 (66% ± 10, range 49–87%) (p < 0.0001). CONCLUSIONS: The Elisée 250 ventilator-user interface was easier to use than that of the Oxylog 3000. The applicability of these results to other types of users will require further studies, but the types of errors found in our study might help future users. Key words: ventilator-user interface, evaluation, mechanical ventilation, transport ventilator, ventilator.

Introduction

Mechanical ventilation is widely used during prehospital care and intrahospital and interhospital transport, but patients who require mechanical ventilation are often unstable, and their transport may be associated with ventilatory function deterioration. Ventilators are recommended that can provide ventilation with the same settings and parameters. Ventilator choices include portable pneumatic ventilators, which are compact and easy to use.
and intensive-care-unit (ICU) ventilators, many of which are bulky and have less autonomy, notably during interhospital transport. Adverse events during transport may be related to improper ventilator use as well as inadequate user training. Use of ICU advanced ventilators by well-trained physicians may limit the risk of adverse events during transport, but not all users have the same expertise in their use.

The ideal advanced compact transport ventilator should have the usual capabilities of an ICU ventilator (volume and pressure ventilation modes, positive end-expiratory pressure, alarms, monitoring) and be autonomous and conveniently portable. The ventilator should also be easy to use and allow rapid and error-free regulation of ventilator settings and parameters, as well as correct identification of alarms and monitoring, but without precise recommendations as far as international standards. Very few studies have evaluated the ventilator-user interface, and none have involved emergency transport ventilators.

The purpose of the present study was to evaluate the ease of use of 2 newer advanced compact transport ventilators. We also asked the participating physicians to evaluate their level of satisfaction with the 2 ventilators.

**Methods**

**Ventilators**

The 2 tested ventilators were the Oxylog 3000 (Dräger, Lübeck, Germany) and the Élisée 250 (ResMed, Savigny le Temple, France). Both ventilators are suitable for use during intrahospital, interhospital, and prehospital patient transport. They have similar features overall, with a few technical differences (Table 1). Their user interfaces, however, are based on 2 different concepts: the Oxylog 3000 has a combination of different types of controls (Fig. 1), whereas the Élisée 250 has a touch-pad (Fig. 2). Compared to most standard transport ventilators, they offer a high performance level and a large choice of settings.

**Study Design**

We conducted a 2-center descriptive study to compare the use of 2 new advanced compact ventilators suitable for

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**Table 1. Comparison of the Main Technical Aspects of the Élisée 250 and Oxylog 3000**

<table>
<thead>
<tr>
<th></th>
<th>Élisée 250</th>
<th>Oxylog 3000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor type</strong></td>
<td>Electrically powered miniaturized turbine</td>
<td>Pneumatically powered (third-generation)</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>4.5</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>Dimensions (cm)</strong></td>
<td>29 × 25 × 13</td>
<td>28.5 × 18.4 × 17.5</td>
</tr>
<tr>
<td><strong>Battery life</strong></td>
<td>4 h on 1 battery, 8 h on 2 batteries</td>
<td>4 h</td>
</tr>
<tr>
<td><strong>Ventilation modes</strong></td>
<td>VC-VAC, AI, VPAC, PEP</td>
<td>VC-VAC-VACI, AI, BIPAP</td>
</tr>
<tr>
<td><strong>I:E setting</strong></td>
<td>Set via inspiratory flow setting</td>
<td>Set directly</td>
</tr>
<tr>
<td><strong>Inspiratory flow setting</strong></td>
<td>Set directly</td>
<td>Set via I:E setting ± end-expiratory pause</td>
</tr>
<tr>
<td><strong>Settings after starting ventilator in volume-controlled mode</strong></td>
<td>Respiratory rate 15 breaths/min, FIO2 60%, PIP 50 cm H2O, Inspiratory flow 50 L/min, PEEP 0 cm H2O, Trigger on at sensitivity level 3</td>
<td>Respiratory rate = setting left by previous user, FIO2 setting left by previous user, PIP setting left by previous user, I:E 0.5, PEEP 4 cm H2O, Trigger off</td>
</tr>
</tbody>
</table>

*According to manufacturer

†For each mode, the meaning of the French abbreviation that appears on the ventilator is indicated below, followed by the English translation:

VC = ventilation contrôlée = CV = controlled ventilation
VAC = ventilation assistée contrôlée = ACV = assist control ventilation
VACI = ventilation assistée contrôlée intermittente = SIMV = synchronized intermittent mandatory ventilation
AI = aide inspiratoire = PSV = pressure support ventilation
VPAC = ventilation en pression assistée contrôlée = PACV = pressure assist control ventilation
BIPAP = Biphasic positive airway pressure (specific mode of Dräger ventilator)
PAM = PEEP = positive end expiratory pressure
I:E = inspiratory-expiratory ratio
EVALUATION OF 2 NEW TRANSPORT VENTILATORS

Three investigators (French senior emergency physicians) collected data from 20 French emergency physicians (10 at each center) who had common training in emergency medicine, but irrespective of their experience or skill with mechanical ventilation or other criteria. Absence of prior experience with the 2 study ventilators was required. The ventilators were tested in random order, using a randomization list and sealed envelopes. Randomization was performed independently at each site. The study data were recorded on a standardized form and then entered into an anonymous computer database created specifically for the study.

Study Procedure

The study involved 4 steps:

Step 1: Emergency Physician Characteristics. Each physician completed a questionnaire about his or her training, ICU experience, and familiarity with the various ventilator types (simple pneumatic ventilators and ICU ventilators).

Step 2: Familiarization With the Study Ventilators. Each emergency physician was initially allowed 15 min with each ventilator. The physicians did not have access to the manuals and were given no explanations. The patient circuit was connected to a balloon. The parameters set on the ventilator after it was turned on in controlled ventilation mode are specified in Table 1. At the beginning of the familiarization period, the physician was instructed to find out how to start and stop the ventilator, how to adjust settings for volumetric modes (inspiratory-expiratory ratio or inspiratory flow), pressure-support ventilation, and positive end-expiratory pressure, what each button on the control panel is for, where the alarm settings are located, and where patient data is displayed.

Step 3: Tasks. In the presence of one of the 3 investigators, the emergency physician tried to perform 15 tasks that correspond to settings and changes frequently encountered during the transport of ventilated patients (Table 2). Each task needed to be completed in less than 120 s (except task 11, for which the time allowance was 180 s). Each task ended when the time allowance was up or when the physician reported that the setting adjustments were confirmed (without noting time). The following were recorded for each individual for each task: task completion without error within the allowed time; task completion with one or more errors within the allowed time; or noncompletion of task. Errors were recorded and categorized as follows. First, by the type of error: A. Failure to find a setting site or display site. B. Confusion with another setting site or display site. C. Setting site identified correctly but inappropriate setting. D. Failure to confirm the settings. Second, the errors were categorized according to their potential risk.
of immediately adversely affecting oxygenation, ventilation, or the patient work of breathing. The errors that could have a potentially immediate adverse effect were grouped as follows: risk of desaturation (incorrect adjustment of fraction of inspired oxygen \([FIO_2]\) or positive end-expiratory pressure); risk of inadequate alveolar ventilation (error in ventilation mode [type, confirmation]) in one of the mode’s parameters (tidal volume or frequency), or the ventilation settings during apnea; risk of provoking patient-ventilator asynchrony (incorrect inspiratory flow, sensitivity of the inspiratory trigger, or the pressurization ramp).

**Step 4: Satisfaction Score.** After the tasks, each physician scored his/her satisfaction with the ventilator, defined as its perceived ease of use. A specific scale was designed, with a maximum of 88 points (4 groups of 22 items), and the score was converted to a percentage.

### Table 2. User Interface Task Results From the Éliseé 250 and Oxylog 3000

<table>
<thead>
<tr>
<th>Number of Physicians Who Completed the Task Without Error Within the Allowed Time (n)</th>
<th>All Physicians (n = 20)</th>
<th>According to Self-Evaluated Expertise With ICU Ventilators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Éliseé 250</td>
<td>Oxylog 3000</td>
</tr>
<tr>
<td>1. Start CV and set I:E</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>2. Set FIO_2</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>3. Set inspiratory flow</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>4. Identify automatic alarm ranges</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>5. Identify control panel set sites</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>6. Identify patient parameter display sites</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>7. Change alarm ranges</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>8. Identify the plateau pressure value</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>9. Shut down the ventilator</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>10. Start ACV (pediatrics) and set inspiratory flow</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>11. Start PSV with PEEP and set apnea ventilation</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>12. Identify exhalation values in PSV</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>13. Switch from PSV with PEEP to ACV</td>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>14. Rapidly and temporarily set FIO_2 to 100%</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>15. Determine battery charge level</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Total (n, %) (300 tasks per ventilator)</td>
<td>257 (85.7)*</td>
<td>200 (66.7)</td>
</tr>
</tbody>
</table>

*Éliseé 250 versus Oxylog 3000 p < 0.001 via chi-square test
†Éliseé 250 versus Oxylog 3000 p < 0.005 via chi-square test
CV = controlled ventilation
I:E = inspiratory-expiratory ratio
FIO_2 = fraction of inspired oxygen
ACV = assist-control ventilation
PSV = pressure support ventilation
PEEP = positive end expiratory pressure

**Statistical Analysis**

We used statistics software (SPSS 11.01, SPSS, Chicago, Illinois) for all the data analysis. The chi-square and paired Wilcoxon tests were selected, based on the type of data. A p value < 0.05 was considered statistically significant.

**Results**

**Participant Characteristics**

At each site, the first 10 French emergency physicians invited to participate in the study accepted; none were familiar with the study ventilators. There were no significant differences between the 2 groups of physicians at the 2 study centers. Their profiles were very similar to that found in other evaluations of French emergency physi-
cians. Their self-evaluation of expertise was good with simple pneumatic ventilators and variable with ICU ventilators (3 physicians said their expertise was limited, 12 said theirs was moderate, and 5 said theirs was good).

**Overall Ventilator Testing Results**

With each ventilator a total of 300 tasks were performed. The percentage of physicians who completed the tasks without any errors was significantly higher with the Elisée 250 (85.6%) than with the Oxylog 3000 (66.6%) (p < 0.001) (see Table 2). The percentage of physicians who completed tasks with errors was smaller with the Elisée 250 (11.6%) than with the Oxylog 3000 (21%) (p = 0.002). The percentage of physicians who did not complete tasks was also lower with the Elisée 250 (2.6%) than with the Oxylog 3000 (12.3%) (p < 0.0001). The error-free completed-task rate was significantly better with the Elisée 250 than with the Oxylog 3000, at all 3 levels of self-evaluated expertise with ICU ventilators (see Table 2). Several different errors could occur in a single task, and the same type of error could occur in different tasks. In all, the total number of errors was 46 with the Elisée 250 and 113 with the Oxylog 3000 (Table 3).

**Types of Errors**

*Failure to Find a Setting Site or a Display Site.* These represented about half of the errors with each ventilator. The main source of error was inspiratory flow adjustment on the Oxylog 3000 (n = 31). Inspiratory-expiratory ratio adjustment errors via flow with the Elisée 250 were less common (n = 11). There were a substantial number of errors in setting the alarm ranges on the Oxylog 3000 (n = 10).

*Confusion With Another Setting Site or Display Site.* Confusion between assist-control ventilation (these ventilators display the acronym VAC for the French term ventilation assistée contrôlée) and synchronized intermittent mandatory ventilation (SIMV, but the ventilator displays the acronym VACI in French) was common with the Oxylog 3000 (n = 17).

**Setting Identified Correctly But Inappropriately Adjusted.** Errors in adjusting the inspiratory trigger occurred with both ventilators and were more common with the Elisée 250 (n = 16) than with the Oxylog 3000 (n = 11).

**Failure to Confirm the Settings.** This error occurred only with the Oxylog 3000 (n = 3).

**Errors With Potentially Immediate Adverse Effects.** Fourteen types of errors were considered as potentially having immediate adverse effects (in Table 3, errors A1–A4, B1, B2, C1–C6, D1, and D2), and of these errors there were a total of 119: 35 with the Elisée 250 (76% of the errors with the Elisée 250) and 84 with the Oxylog 3000 (74.3% of the errors with the Oxylog 3000). Four types of errors represented about three fourths of these 119 errors.
(A1, A2, B1, and C5), which were twice as common with the Oxylog 3000 \( (n = 59) \) as with the Elisée 250 \( (n = 29) \).

**Satisfaction Score**

The satisfaction score was significantly better with the Elisée 250, both overall and for each group of items (Table 4). About three fourths of the physicians said they would be willing to use both ventilators immediately or after receiving specific hands-on training, but the willingness to use the ventilator without training was more common with the Elisée 250. One physician was unwilling to use the Oxylog 3000. We did not research the correlation between the satisfaction score and the percentage of task successes.

**Discussion**

Our study shows that for this group of French emergency physicians, who participated and in the absence of
specific training, the Eliseé 250 proved significantly easier to use, with fewer errors than the Oxylog 3000.

Several studies have compared the technical performance of ventilators, but data on the ventilator-user interface are scarce and available only for ICU and home ventilators or for a single element of the interface. To our knowledge, the present study is the first to study advanced compact transport ventilators. The importance of a user-friendly interface in ensuring easy and safe ventilator use was recently underscored, and interface evaluations are recommended in addition to performance evaluations.

**Limitations**

The present study has several possible limitations. First, though the profile of the participants was representative of all French emergency physicians, we cannot directly apply these results to other categories of users (eg, ICU physicians, emergency physicians in countries other than France, respiratory therapists, or emergency nurses). The difference between the ease of use of the 2 ventilators, however, was also found in the present study among the physicians familiar with ICU ventilators.

Second, testing only 2 ventilators may seem like too few, compared to other studies. We had very strict criteria in choosing a ventilator, and they were representative of practical needs: compact, advanced, and with good performance, as defined in the study methods. Ventilators that did not match our criteria were not considered and we also eliminated ventilators not available in France. The 2 ventilators we did test are available almost worldwide. The LTV 1000 (Pulmonetic Systems, Colton, California) could have been included, given our criteria, but we did not test it because many emergency physicians here are familiar with it.

Third, there is no standard methodology for this type of study, which required us to choose our methods. We followed general recommendations, observing the users, evaluating task success rate, and categorizing errors according to potential consequences. The tasks chosen were representative of practical requirements (adjustments, monitoring) and of recommendations for patient transport. The small number of ventilators tested allowed us to test 15 tasks per ventilator, whereas other studies have looked at only 6 or 7 tasks.

Fourth, the physicians did not have access to the ventilator manuals and received no explanations about the ventilators. In theory, physicians should receive training before using a new ventilator. In practice, however, training may be cursory, and we sought to replicate this situation. In addition, some physicians have few opportunities to use ventilators and may therefore forget some of their initial training.

**Analysis of Overall Results**

In the conditions of our study, the Eliseé 250 was significantly easier to use than the Oxylog 3000. This is probably due to the difference in concept between the 2 interfaces (a touch-pad vs a combination of various types of controls). The small size of these ventilators may complicate the search for ideal ergonomics as well. The touch-pad of the Eliseé 250 allows for placement of different categories of parameters on different distinct screens. The letters can be larger, which facilitates recognition. Adjusting a setting is simpler because the user does not have to manipulate multiple controls of different types. The Oxylog 3000 allows direct access to basic adjustments, similar to those on simple pneumatic ventilators (tidal volume, respiratory rate, maximum inspiratory pressure, and FiO2), which could be advantageous in emergencies. Yet the physician errors in making these basic settings (frequency, tidal volume) were more frequent than with the Eliseé 250. For advanced parameters, manipulating different types of controls is often necessary to visualize or confirm a given parameter. This undoubtedly represents a potential source of confusion and error for the new or occasional user.

**Analysis of Errors According to Different Types**

**Failure to Find a Setting Site or Display Site.** This error type constituted half of all the errors. The indirect adjustment of a requested setting appears to be one source of difficulty. One example is the high error rate in adjusting the inspiratory flow on the Oxylog 3000. One must adjust the inspiratory-expiratory ratio and, often, also the end-inspiratory pause.

**Confusion With Another Setting Site or Display Site.** The most common error was choosing SIMV (French acronym VAC) mode rather than assist-control ventilation (French acronym VAC) on the Oxylog 3000, which resulted in ventilation with an inappropriately increased inspiratory-expiratory ratio (inspiratory time lengthened by default in VACI). The absence of the acronym ACV (for assist-control ventilation) next to the label for assist-control ventilation on the access button for this mode might explain this, especially since the French acronyms VAC and VACI are so similar. Identifying this type of user-interface defect would allow the manufacturer to make simple, rapid, and efficient corrections.

**Setting Identified Correctly But Inappropriately Adjusted.** Inappropriate setting of inspiratory trigger sensitivity was fairly common. On the Eliseé 250, the technology of the trigger does not depend on detection of the flow or pressure, but on the gradient of the pressure drop. Therefore, no units are marked, which might contribute to
errors. Clear indication on the controls of the trigger sensitivity (eg, from “very sensitive” to “least sensitive”) might reduce this type of error.

### Analysis of Errors With Potentially Immediate Adverse Effects

To our knowledge, the distinction between errors that might or probably would not have immediate adverse effects has not previously been used in this type of study. Nevertheless, many clinical studies have stated the importance of the correct adjustment of these parameters for optimal mechanical ventilation.19–23 In the present study these errors were frequent (3 out of 4) and they happened twice as often with the Oxylog 3000 (see Table 3). The reasons for these errors are probably the same as those previously noted, including the advantage of directly adjusting the essential parameters, advantage of grouping the same functions on one screen, and the advantage of not having many different types of control buttons. Therefore, in the context of our study, the risk of an error that might have an adverse clinical effect appeared to be higher with the Oxylog 3000. We did not consider error A8 (determination of battery charge) as potentially having immediate adverse effect, because both ventilators have a low-battery sound alarm that gives the user time to react appropriately.

### Analysis of Satisfaction Scores

Both the overall satisfaction score and the subscores were significantly better with the Elisée 250. Nearly all the participating physicians said they would be willing to use either ventilator, although the demand for additional training was greater with the Oxylog 3000. We did not study the possible influence that previous experience with other ventilators might have had on the score. Since touch-pad technology is a relatively recent development, one could postulate that the physicians were less accustomed to it. This would not have given it any score advantage. The relationship between the satisfaction score and the success rate in the tasks was not studied, but this might be interesting to include in future similar studies.

### Conclusions

This limited study of 20 volunteer emergency physicians in France found that the Elisée 250 user interface was easier to use, and therefore more reliable than the Oxylog 3000 user interface. These results cannot be directly applicable to other types of users without further studies. Studies of the ease and dependability of use of different types of ventilators with different types of users should be done more often, to improve the ergonomics of the user interface, with special attention to the types of errors that occurred in our study, especially those with immediate adverse effects.

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### REFERENCES

