Retained tracheobronchial secretions are common in patients receiving mechanical ventilation (MV) because of impaired cough reflex, depressed mucociliary clearance, and increased mucus production. Tracheal suction (TS) is therefore periodically warranted to prevent airway and tracheal tube obstruction and to decrease the work of breathing when patients are spontaneously breathing. Systematic TS cannot be advised because of its complications, such as bronchoconstrictor response, hypoxemia, cardiac arrhythmias or cardiac arrests, and mucosal damage. TS should preferably be performed on an as-needed basis. However, very few
studies have examined how to detect retained secretions in patients receiving MV.\textsuperscript{7–9} Jubran and Tobin\textsuperscript{7} report that the presence of a sawtooth pattern on a flow-volume loop can accurately predict retained secretions in intubated patients. However, the study was conducted in conditions that strongly differ from daily ICU practice. Indeed, patients were spontaneously breathing through their tracheal tube while disconnected from the ventilator; flow-volume loops were obtained from external respiratory physiology apparatus but not from the ventilator monitor screen, and were analyzed \textit{posteriori}. The presence of respiratory sounds over the central airways may also indicate retained secretions, but this assumption relies on old and incomplete studies.\textsuperscript{8,9} Patient agitation, decrease in pulse oximetric saturation (Sp\textsubscript{O2}), or modifications of ventilatory pattern such as increase of peak inspiratory pressure (Ppeak) in volume-controlled mode or decrease of tidal volume (V\textsubscript{T}) in pressure-controlled mode are believed to indicate retained secretions.\textsuperscript{1} However, to our knowledge, none of these parameters have been validated in daily clinical practice.

The aim of this prospective study was to determine which parameters among the presence of a sawtooth pattern, the presence of respiratory sounds, Sp\textsubscript{O2} drop, patient agitation, and modifications of the respiratory pattern could reliably detect retained secretions in critically ill patients receiving MV.

### Materials and Methods

The study was performed in a 14-bed medical ICU of Saint-Antoine Hospital, a 946-bed university hospital. It was conducted according to the local Ethics Committee Guidelines for Human Research. Informed consent was obtained from each patient or the nearest next of kin.

All consecutive patients receiving MV with the Cesar ventilator (CFPO; Paris, France) or the T-Bird ventilator (SEBAG; Pantin, France) were included. Both ventilators display real-time flow-volume loops on their monitor screen. Either volume-cycled ventilation or pressure-support ventilation was used. During volume-cycled ventilation, V\textsubscript{T} was set at 6 to 8 mL/kg and respiratory rate at 15 to 20 breaths/min. During pressure-support ventilation, the pressure level was set to obtain a V\textsubscript{T} \(> 6\) mL/kg and a respiratory rate \(< 30\) breaths/min. MV was administered through a cuffed translaryngeal tube or through a cuffed tracheostomy tube. No changes of individual respiratory settings were made for the purpose of the study. Patients were studied in the supine position with a 30° head-lift inclination. No sedation was specifically used for the purpose of the study. When it was deemed necessary by the attending physician, IV midazolam and/or fentanyl were used and titrated to achieve a Ramsay score of 3 or 4.\textsuperscript{10}

The experimental procedure was as follows. After the first TS (TS1) was performed by the attending nurse, two of the investigators (J.G. and M.A.) not involved in the suctioning procedure recorded the Ramsay score (ranging from 1 to 6), Ppeak, V\textsubscript{T}, and Sp\textsubscript{O2}. The investigators were unblinded to the results of the procedure. Ppeak and V\textsubscript{T} were obtained from the monitor screen of the ventilator and were a mean of at least three successive respiratory cycle measurements. Immediately before the second TS (TS2) performed by the nurse as usual patient care, the same parameters were recorded twice by the same investigators, and the variations of Ramsay score, Ppeak, V\textsubscript{T}, and Sp\textsubscript{O2} between the two TSs were calculated. The presence of respiratory sounds and of a sawtooth pattern was also noted before TS2. Respiratory sounds were heard with a stethoscope over the trachea, above the sternum. Only respiratory sounds heard during the expiratory phase of the respiratory cycle were considered. They were either rhonchi or coarse, gurgling sounds. At least three successive flow-volume loops were analyzed before deciding if a sawtooth pattern was present. The sawtooth pattern is a reproducible sequence of alternating decelerations and accelerations of flow superimposed on the general contour of the flow-volume loop easily distinguishable from the smooth contour of the normal flow-volume loop (Fig 1).\textsuperscript{11} Care was taken before flow-volume loop analysis to remove water or secretions in the ventilator tubing.

For the first 20 patients, the flow-volume loops and the respiratory sounds were independently assessed by two of the investigators (J.G. and M.A.). Before each tracheal suctioning, they independently examined flow-volume curves. The result of each analysis was considered concordant if both observers agreed about the presence or about the absence of a sawtooth pattern. The result was considered discordant if one observer identified a sawtooth pattern but the other did not. No discordant results between the two observers were observed. An identical approach was used for analysis of respiratory sounds and, again, no

![Figure 1. Schematic aspect of the flow-volume loop in a patient without retained secretions (left panel) and in a patient with retained secretions (right panel); note the smooth contour of the loop in the patient without secretions and the sawtooth pattern of the contour in the other patient.](image-url)
discordant results between the two observers were observed. For the rest of the patients, only one of the investigators (J.G.) assessed these parameters.

TS1 was performed with a 16F suction catheter (Sherwood Medical; Tullamore, Ireland). TS2 was also performed with a 16F catheter, but with a reservoir device inserted between the vacuum source and the catheter (Cair Laboratory; Civrieux d’Azerqnes, France). The lubricated catheter was inserted through a suction catheter adapter allowing no flow interruption during the procedure (Mallinckrodt Medical; Mirandola, Italy). It was advanced until a resistance was met. A negative pressure of −200 cm H2O was then applied, and the catheter was rotated and gradually removed. Suction was interrupted when the catheter reached the external outlet of the adapter. The catheter was rinsed with 10 mL of saline solution, and the secretions collected in the reservoir were measured with graded syringes.

Statistical and Data Analysis

The “gold standard” used to define retained secretions was a volume of removed secretions by TS2 of >0.5 mL. This threshold value was chosen according to previous studies. Results are expressed as means ± SD. Percentage of variations between TS1 and TS2 of SpO2, Ppeak, and Vt (ratio of value before TS2 minus value after TS1) were compared between patients with TS2 ≤ 0.5 mL (group 1) and patients with TS2 > 0.5 mL (group 2) with a bilateral Student’s t test. For patients receiving volume-cycled ventilation, only Ppeak variations were studied; for patients receiving pressure-support ventilation, only Vt variations were considered. Absolute variations of Ramsay score between TS1 and TS2 (value before TS2 minus value after TS1) were compared between the two groups with a bilateral Student’s t test. The presence of a sawtooth pattern and of respiratory sounds before TS2 was compared between the two groups with a χ2 test. A p value < 0.05 was considered statistically significant.

Calculations of sensitivity, specificity, positive predictive value, and negative predictive value were standard formulas. The likelihood ratio of a positive test was calculated as (sensitivity/specificity). The likelihood ratio of a negative test was calculated as [(1 – sensitivity)/specificity].

RESULTS

Sixty-six patients were studied. Their characteristics are presented in Table 1. Thirty-nine patients (59%) had TS2 > 0.5 mL (group 2). The mean volume of removed secretions by TS2 was 2.6 ± 2.5 mL (range, 0.6 to 12 mL) in group 2, and 0.1 ± 0.1 mL (range, 0.0 to 0.5 mL) in group 1. The mean time elapsed between TS1 and TS2 was 122 ± 38 min.

Variations of Ppeak, Vt, SpO2, and Ramsay score between TS1 and TS2 did not differ between the two groups (Table 2). However, group 2 had a sawtooth pattern (82% vs 29.6%; p = 0.0001) and respiratory sounds (66.6% vs 25.9%; p = 0.001) more frequently than group 1 before TS2.

The likelihood ratio of the presence of a sawtooth pattern before TS2 to indicate retained secretions was 2.70, while the likelihood ratio of a negative test was 0.25 (Table 3). For respiratory sounds, the ratios were 2.50 and 0.45, respectively. When a sawtooth pattern and respiratory sounds were both present, the likelihood ratio of a positive test rose to 14.7, but the likelihood ratio of a negative test was only 0.42.

Table 2—Variations of Ppeak Concern Patients Receiving Volume-Cycled Ventilation (n = 35), and Variations of Vt Concern Patients Receiving Pressure-Support Ventilation (n = 31)∗

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group 1 (n = 27)</th>
<th>Group 2 (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ppeak, %</td>
<td>3.4 ± 20.0</td>
<td>6.3 ± 24.2</td>
</tr>
<tr>
<td>Vt, %</td>
<td>−2.8 ± 8.3</td>
<td>−8.5 ± 22.5</td>
</tr>
<tr>
<td>SpO2, %</td>
<td>0.03 ± 3.00</td>
<td>−0.40 ± 2.70</td>
</tr>
<tr>
<td>Ramsay score, U</td>
<td>−0.11 ± 0.80</td>
<td>−0.15 ± 0.78</td>
</tr>
<tr>
<td>Respiratory sounds</td>
<td>7 (23.9)</td>
<td>26 (66.6)†</td>
</tr>
<tr>
<td>Sawtooth pattern</td>
<td>8 (29.6)</td>
<td>32 (82.1)‡</td>
</tr>
<tr>
<td>Sawtooth pattern and respiratory sounds</td>
<td>1 (3.7)</td>
<td>23 (58.9)†</td>
</tr>
</tbody>
</table>

*Data are presented as means ± SD or No. (%).
†p = 0.001.
‡p = 0.0001.

DISCUSSION

In this prospective study, we observed that the presence of a sawtooth pattern on the flow-volume loop displayed on the monitor screen of the ventilator or the presence of respiratory sounds over the trachea accurately indicates the presence of retained tracheobronchial secretions in ICU patients receiving MV, and may indicate the need for TS. Conversely, modifications of the respiratory pattern, SpO2, or Ramsay score fail to identify patients with retained secretions.

The sawtooth pattern is a reproducible sequence of alternating decelerations and accelerations of flow superimposed on the general contour of the flow-volume loop easily distinguishable from the smooth
The sawtooth pattern is reported in a variety of diseases affecting the upper airways and is thought to result from intermittent changes in airway resistances. In patients receiving MV, Jubran and Tobin\(^7\) have demonstrated that the sawtooth pattern results from accumulation of tracheobronchial secretions and could indicate the need for TS. However, as mentioned above, the experimental design of their study differed strongly from daily ICU practice and could not be a priori extrapolated to common ICU situations. In the current study, a sawtooth pattern was 2.70 times more likely to be observed in patients with retained secretions than in patients without secretions. Conversely, the absence of a sawtooth pattern was about one fourth as likely to be found in patients with secretions as in those without secretions. The likelihood ratio was used because it is a powerful means of determining the predictive value of a diagnostic test. It relies only on the intrinsic characteristics of the diagnostic test (sensitivity and specificity) and is therefore independent of the prevalence of the “disease” (ie, retained secretions).\(^{12,13}\) The main striking difference between the results of Jubran and Tobin\(^7\) and our results is the lowest value for the likelihood ratio of a positive test. Indeed, Jubran and Tobin\(^7\) reported a likelihood ratio of a positive test ranging from 5.5 to 7.9. This difference relies on our low specificity and results from higher false-positive results: 25% in our study vs 12% in the study by Jubran and Tobin.\(^7\) False-positive results can arise from the presence of water or secretions in the ventilator tubing. Although care was taken to remove them before analyzing flow-volume curves, we cannot exclude that they were not totally removed. The only way to eliminate this artifact would have been to change the ventilator tubing before each recording, an unrealistic procedure for a diagnostic test that has to be used easily in clinical practice.

 Accumulation of secretions in the trachea and in the central airways leads to the production of respiratory sounds. The presence of respiratory sounds can indicate the need for TS as suggested by previous studies.\(^8,9\) In the current study, respiratory sounds over the trachea were 2.50 times more likely to be heard in patients with retained secretions than in patients without secretions. Conversely, absence of respiratory sounds was about one half as likely to be heard in patients with secretions as in those without secretions.

Patient agitation, \(\text{SpO}_2\) drop, and modification of the respiratory pattern are classically believed to indicate retained secretions and the need for TS.\(^1\) However, we failed to detect any differences in these parameters between the two groups of patients, although we observed a trend toward a greater increase between the two suctioning procedures of \(P_{\text{peak}}\) in patients with retained secretions (6.3% vs 3.4%). The time elapsed between the two procedures (about 2 h) may account for this lack of difference. It is probably a short delay, to allow enough secretions to accumulate and to lead to the symptoms of increased \(P_{\text{peak}}\), decreased \(V_t\), patient agitation, and \(\text{SpO}_2\) drop. However, in order to ensure patient safety, we believe that the nursing or medical staff cannot rely on these late signs of retained secretions to perform TS.

The likelihood ratios of a positive test for sawtooth pattern and for respiratory sounds are very close, suggesting that their ability to detect retained secretions is similar. On the contrary, the decision to postpone TS should more reliably be based on the absence of a sawtooth pattern than on the absence of respiratory sounds, because of the lower likelihood ratio of a negative test for the absence of a sawtooth pattern. Combination of the presence of sawtooth pattern and respiratory sounds will more accurately identify patients with retained secretions, but does not add to the likelihood ratio of a negative test.

In summary, the presence of a sawtooth pattern on flow-volume loop displayed on the monitor screen of the ventilator and/or the presence of respiratory sounds over the trachea are good indicators of retained secretions in patients receiving MV and may indicate the need for TS. Conversely, the absence of a sawtooth pattern may rule out retained secretions. Efforts should be made to educate the nursing team and respiratory therapists to monitor respiratory sounds and to analyze flow-volume loops.

Table 3—Accuracy of Sawtooth Pattern, Respiratory Sounds, and Combination of Sawtooth Pattern and Respiratory Sounds to Detect Retained Secretions

<table>
<thead>
<tr>
<th>Variables</th>
<th>Sawtooth Pattern</th>
<th>Respiratory Sounds</th>
<th>Combined Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>0.82</td>
<td>0.66</td>
<td>0.59</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.70</td>
<td>0.74</td>
<td>0.96</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>0.80</td>
<td>0.75</td>
<td>0.96</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>0.73</td>
<td>0.60</td>
<td>0.62</td>
</tr>
<tr>
<td>Likelihood ratio of a positive test</td>
<td>2.70</td>
<td>2.50</td>
<td>14.7</td>
</tr>
<tr>
<td>Likelihood ratio of a negative test</td>
<td>0.25</td>
<td>0.45</td>
<td>0.42</td>
</tr>
</tbody>
</table>

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