

Performance Analysis of the Flutter VRP1 Under Different Flows and Angles

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BACKGROUND: The Flutter VRP1 device is used for airway clearance. Its performance is based on 4 basic effects: positive expiratory pressure (PEP), forced exhalations (huff), high-frequency airway flow oscillation, and modification of mucus viscoelasticity. The purpose of this study was to determine the flow and angle conditions in which these effects are optimized. **METHODS:** In an experimental setting, a Flutter VRP1 was fixed at angles of -30° , -15° , 0° , $+15^\circ$, and $+30^\circ$, and submitted to flows ranging from 0.2 L/s to 2.0 L/s. The flows and angles that resulted in higher and lower values of mean pressure, mean flow, oscillation frequency, and flow amplitude were determined. In addition, it was defined which angles facilitated achieving “ideal” mean pressure of 10 cm H₂O and 20 cm H₂O and oscillation frequency of 12 Hz. **RESULTS:** At all flows, $+15^\circ$ produced higher mean pressure ($p < 0.01$), whereas lower values were produced at -30° at lower flows, 0° at intermediate flows, and $+30^\circ$ at higher flows ($p < 0.01$). Higher oscillation frequencies were produced at $+30^\circ$ and $+15^\circ$ ($p < 0.01$), and lower values were produced at -30° and -15° at all flows ($p < 0.01$). Higher flow-amplitude values were produced at $+30^\circ$, $+15^\circ$, and 0° ($p < 0.01$), and lower values were produced at -30° and -15° ($p < 0.01$). Mean pressure of 10 cm H₂O was reached with the lowest flow (0.2 L/s) at $+30^\circ$, and mean pressure of 20 cm H₂O was produced at $+15^\circ$ (1.0 L/s), whereas an oscillation frequency of 12 Hz was reached at 0° , $+30^\circ$, and $+15^\circ$, at 0.2 L/s. **CONCLUSIONS:** Positive inclinations optimize positive expiratory pressure and flow-amplitude effects, whereas negative inclinations optimize huff effect. This theoretical knowledge may help optimize the use of the device when applied to different conditions. *Key words:* physical therapy modalities, respiratory therapy, equipment design, Flutter, secretion clearance, positive expiratory pressure, high-frequency airway oscillation. [Respir Care 2008;53(3):316–323. © 2008 Daedalus Enterprises]

Introduction

The Flutter VRP1 (Varioraw, Aubonne, Switzerland) is a high-frequency airway pressure oscillation device used in respiratory therapy for the purpose of airway clearance.

Its effect is based on flow and pressure oscillation, which is produced by a steel ball kept on a conical seat during a forced expiration performed into the device’s mouthpiece.¹ The oscillations and the resultant changes of this flow and pressure are transmitted to the airways, which facilitates the mobilization of bronchial mucus.

SEE THE RELATED EDITORIAL ON PAGE 311

In theory, airway clearance is facilitated by the Flutter VRP1 due to 4 potential basic effects generated by the

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device: (1) its capacity to produce a positive expiratory pressure (PEP) in the airways,² (2) the occurrence of expiratory flow, which produces a maneuver of forced exhalation known as huff,³ (3) the application of flow oscillations,⁴ and (4) the modification of bronchial mucus viscoelasticity by vibration, which facilitates its mobilization.^{1,5,6} Different studies showed the usefulness of the Flutter VRP1 in increasing the volume of expectorated mucus and improving symptoms in patients with cystic fibrosis,⁶⁻⁸ as well as enhancing the bronchodilator response in patients with chronic obstructive pulmonary disease,⁹ and also restoring lung volumes in healthy subjects.¹⁰

Though the evidence of its effectiveness has been seen in clinical studies that made use of the Flutter VRP1, marketing material and instructions provided by the manufacturer show an incomplete description of the device's characteristics and a lack of more detailed instructions about its use. These instructions only recommend therapists to ask their patients to perform a partially forced expiration at an angle that produces the maximum sensation of vibration,¹¹ which corresponds to resonance frequency of the chest wall and may lead to more effectiveness.⁷ However, detailed information concerning the flow and the device's inclination in relation to a horizontal plane, which are conditions that actually affect the physical principles of the device operation,^{1,4,12,13} are not taken into consideration in any other study.

This lack of information is explained by the insufficient knowledge about how inclination and flow influence each operational physical variable of the device (mean pressure, mean flow, oscillation frequency, and flow amplitude) and how these physical variables affect the device's performance, possibly optimizing its effects (PEP, huff, flow amplitude, and high-frequency airway oscillation) and influencing the mobilization of bronchial mucus. Thus, the purpose of this study was to quantify the physical variables involved in the Flutter VRP1's performance at different flows and angles, and to determine which flow and angle conditions optimize the device's airway clearance effects.

Methods

The study comprised an experimental setup under *in vitro* conditions, with analysis of the physical variables of a non-previously-used Flutter VRP1 device. Different physical variables related to the device were assessed and compared in various situations of angle positioning and flow.

Equipment

In order to produce expiratory flows, a manually operated compressed oxygen source with pressure valve was used. Pressure values were monitored and recorded by a

system with a pressure transducer ± 300 mm Hg (Lynx Tecnologia Eletrônica, São Paulo, Brazil) and data-acquisition software (AqDados 4, Lynx Tecnologia Eletrônica, São Paulo, Brazil), with a sample rate of 100 Hz. Prior to the protocol, the system was calibrated with the use of a mercury column.

Flow values were monitored and recorded by a turbine sensor of a portable spirometer (Pony FX, Cosmed, Rome, Italy), connected to a computer. The equipment received the flow data in real time, at a frequency of 100 Hz, recording and exporting the data to the computer. The system calibration was done by the manufacturer. All equipment was interconnected to the Flutter VRP1 via a flexible duct and adapters.

Setup

A comprehensive description of the equipment setup is shown in Figure 1. The Flutter VRP1 was fixed on a horizontal surface with its mouthpiece positioned at angles of -30° , -15° , 0° , $+15^\circ$, and $+30^\circ$ in relation to the horizontal line, as proposed by Lindermann.¹ This configuration allows the steel ball to be vertically upheld on the conical seat when the device is at $+30^\circ$ and on the minimum support when the device is at -30° . The continuous pressure in the internal chamber produced fast changes in the air flow, creating a gravity-based vibratory behavior.¹

Data Acquisition

After installing the Flutter VRP1 at the respective angle and turning on the pressure and flow acquisition equipment, constant flows of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 L/s were supplied. After 20 s of stabilization at each flow, a data acquisition was done for 20 s. The first 15 s of data acquisition (after the 20 initial seconds of stabilization) were used for analysis, divided into 5 samples of 3 s (Fig. 2). The physical variables assessed in each situation of angle positioning and flow were then compared.

Device Settings

1. Mean pressure: mean pressure applied during flow production, which value depends, fundamentally, on air-flow resistance imposed by the device. This airway pressure creates the PEP effect. The values between 10 and 20 cm H₂O are effective, although the values above 20 cm H₂O suggest more effectiveness.¹⁴ As the mean pressure and mean flow relationship developed, the device's mean resistance was assessed in all situations of flow and angle.

2. Mean flow: mean flow values of constant flows supplied by the compressed oxygen source and monitored by a spirometer (0.2 L/s to 2.0 L/s). Fast or slow flows produce the huff effect.

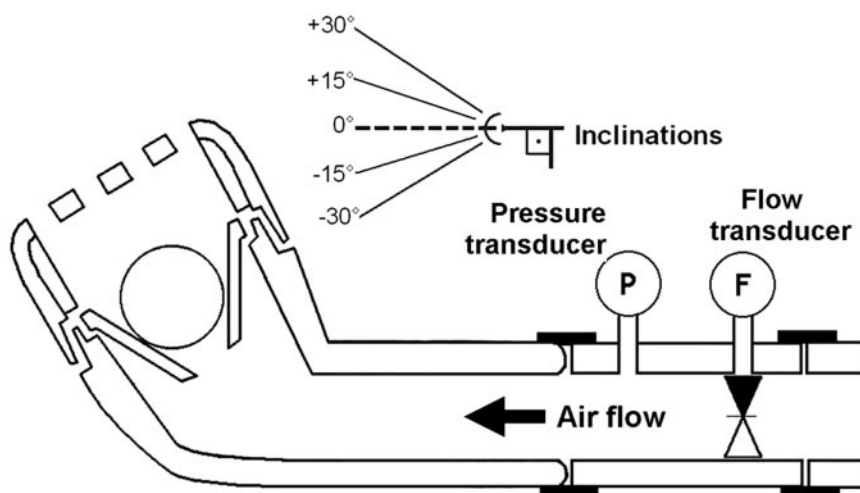


Fig. 1. Characteristics of the equipment and angles of inclination used in the protocol.

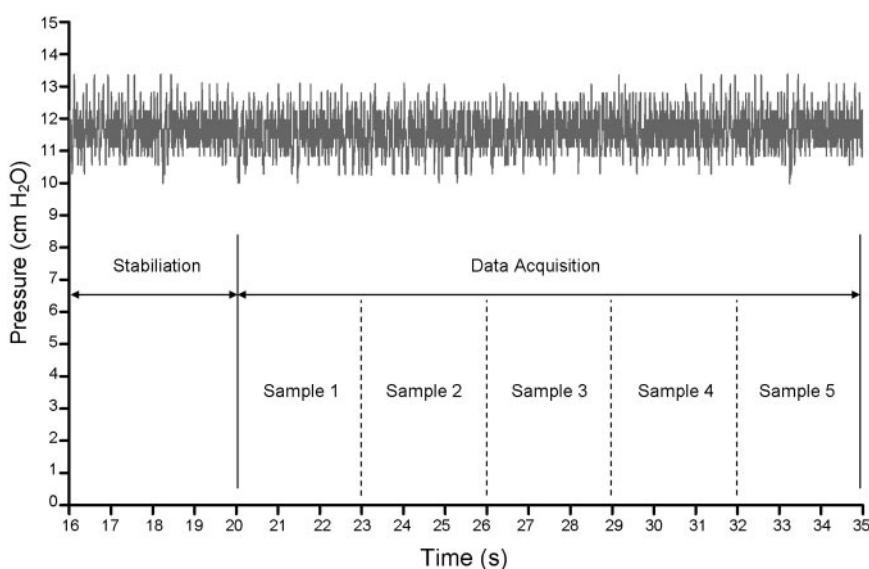


Fig. 2. Example of data acquisition from the Flutter VRP1 setup at +30° and 0.2 L/s. Mean pressure, mean flow, oscillation frequency, and flow amplitude were sampled every 3 s and grouped (5 samples for each variable) for further analysis.

3. Oscillation frequency: number of oscillations per second, measured via visual inspection of the recorded pressure versus time graph. Evidence suggests that values above 12 Hz produce larger alterations in bronchial mucus rheology.¹⁵

4. Oscillatory flow amplitude: mean difference between lower and higher flow values measured by visual inspection of the recorded flow versus time graph. Airway clearance is presumably enhanced by flow oscillations.

Statistical Analysis

For any determined angle and flow, 5 samples of mean pressure, mean resistance, mean flow, oscillation frequency, and flow amplitude were recorded in order to determine:

A: Which angles produced higher and lower mean values of mean pressure, mean resistance, mean flow, oscillation frequency, and flow amplitude at each flow. For this analysis, all values of produced mean pressure, mean resistance, mean flow, oscillation frequency, and flow amplitude were grouped according to the respective angle and flow applied (5 different angles with 10 different flows; total of 50 groups for each variable; 5 samples per group). One-way analysis of variance via Kruskal-Wallis test was used, followed by Bonferroni post hoc test when indicated, to verify differences between the 2 lower and the 2 higher values of mean pressure, mean resistance, mean flow, oscillation frequency, and flow amplitude at 2 given angles at each

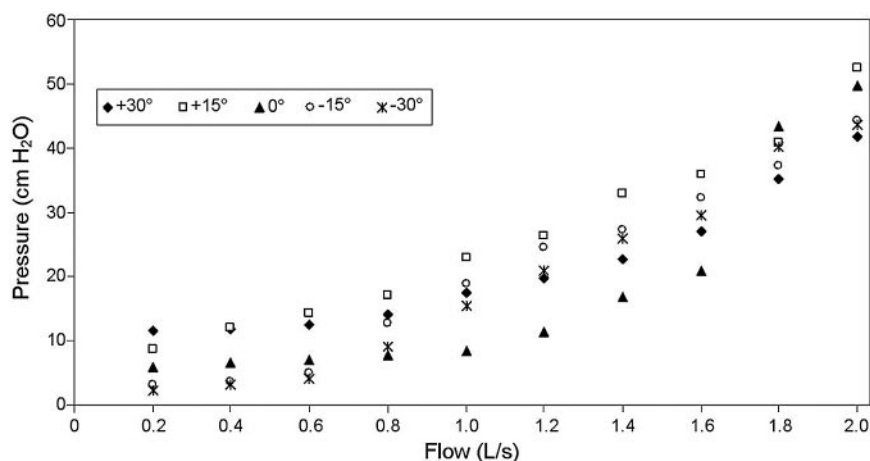


Fig. 3. Mean pressure developed by the Flutter VRP1 at all angles and all flow rates. Each point represents a mean of 5 values of mean pressure. There were statistically significant differences between all values of mean pressure ($p < 0.01$). The angle of $+15^\circ$ produced higher mean pressure values ($p < 0.01$) at the majority of flow rates, whereas the lower values were produced at -30° at lower flows ($p < 0.01$), 0° at intermediate flows ($p < 0.01$), and $+30^\circ$ at higher flows ($p < 0.01$).

flow. Differences were considered statistically significant when $p < 0.05$.

B: Which angle favored the occurrence of a mean pressure between 10 and 20 cm H₂O and the occurrence of an oscillation frequency of 12 Hz with lower flows. For this the lower flow values at each angle that reached mean pressures of 10 and 20 cm H₂O or oscillation frequency of 12 Hz were recorded and descriptively reported.

Results

Mean pressure produced by the device at each angle and flow is shown in Figure 3. It was observed that the higher values of mean pressure at 0.2 L/s and 0.4 L/s were not different ($p = 0.5$), but after the latter value, mean pressure increased according to the flow increase. With the majority of flow rates, the angle of $+15^\circ$ produced higher mean pressure values ($p < 0.01$), whereas the lower values were produced at -30° at lower flows (0.2–0.6 L/s, $p < 0.01$), 0° at intermediate flows (0.8–1.6 L/s, $p < 0.01$), and $+30^\circ$ at higher flows (1.8–2.0 L/s, $p < 0.01$).

In order to reach a target mean pressure of 10 cm H₂O, the lower flow rates at each inclination were, respectively, 0.2 L/s at $+30^\circ$, 0.4 L/s at $+15^\circ$, 1.2 L/s at 0° , 0.8 L/s at -15° , and 1.0 L/s at -30° . To reach a mean pressure of 20 cm H₂O required 1.2 L/s at $+30^\circ$, 1.0 L/s at $+15^\circ$, 1.6 L/s at 0° , 1.2 L/s at -15° , and 1.2 L/s at -30° .

Mean resistance obtained at each flow and angle is shown in Figure 4. Higher mean resistance was obtained at $+15^\circ$ of inclination in the majority of flows ($p < 0.01$), although the greatest absolute value (58 cm H₂O/L/s) was observed at $+30^\circ$ and 0.2 L/s ($p < 0.01$). Lower values of mean resistance were obtained at -30° at lower flows (0.2–0.6 L/s, $p < 0.01$), at 0° at intermediate flows (0.8–1.6 L/s,

$p < 0.01$), and at $+30^\circ$ at higher flows (1.8 and 2.0 L/s, $p < 0.01$). The lower absolute value of mean resistance (7 cm H₂O/L/s) was observed at -30° and 0.6 L/s ($p < 0.01$).

Mean values of the oscillation frequency at each flow and angle are shown in Figure 5. At $+30^\circ$ the higher values of oscillation frequency at lower-to-intermediate flows (0.2–1.0 L/s, $p < 0.01$) were found, whereas at $+15^\circ$ the higher values at intermediate-to-higher flows (1.0–2.0 L/s, $p < 0.01$) were found. The higher absolute value of oscillation frequency (31 Hz) was obtained at $+15^\circ$ and 2.0 L/s ($p < 0.01$). Lower values of oscillation frequency occurred at -30° and -15° with all flows ($p < 0.01$).

In order to reach an oscillation frequency of 12 Hz, the lower values of flow at each angle were, respectively, 0.2 L/s at $+30^\circ$, $+15^\circ$, 0° , and -15° and 1.0 L/s at -30° .

Mean values of flow amplitude at each flow and angle are shown in Figure 6. Higher values of flow amplitude were obtained at 0° at lower-to-intermediate flows (0.2–1.2 L/s, $p < 0.01$) and at $+15^\circ$ and $+30^\circ$ at higher flows (1.4–2.0 L/s, $p < 0.01$). The highest absolute value (0.182 L/s) was found at $+15^\circ$ and 1.4 L/s ($p < 0.01$). The lower values of flow amplitude were found at -30° and -15° ($p < 0.01$). After 1.6 L/s the higher values of flow amplitude flattened out and were not altered significantly ($p = 0.13$ between 1.6 L/s and 1.8 L/s, and $p = 0.5$ between 1.8 L/s and 2.0 L/s).

Discussion

By analyzing the physical variables related to the Flutter VRP1 performance, the present study aimed to determine in which inclinations and flows its airway clearance effects are likely to be optimized. The results demonstrate

PERFORMANCE ANALYSIS OF THE FLUTTER VRP1

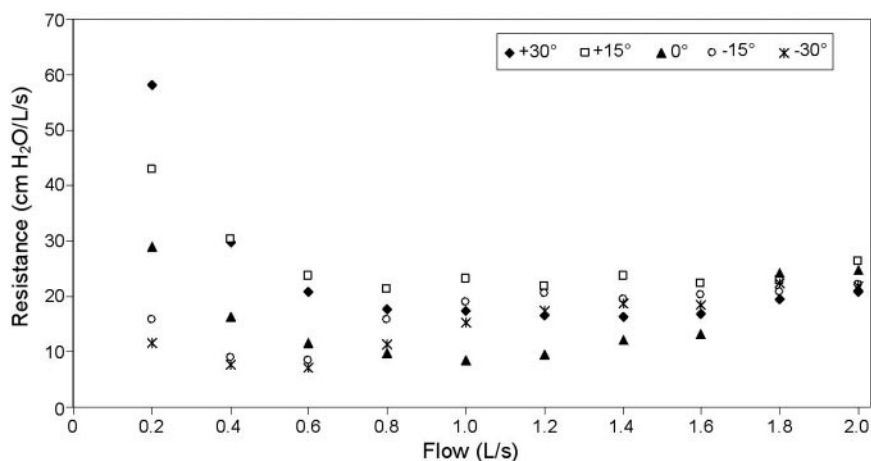


Fig. 4. Mean resistance developed by the Flutter VRP1 at all angles and all flow rates. Each point represents a mean of 5 values of mean pressure. There were statistically significant differences between all values of mean resistance ($p < 0.01$). The angle of $+15^\circ$ produced higher mean resistance values ($p < 0.01$) at the majority of flow rates, whereas the lower values were produced at -30° at lower flows ($p < 0.01$), 0° at intermediate flows ($p < 0.01$), and $+30^\circ$ at higher flows ($p < 0.01$).

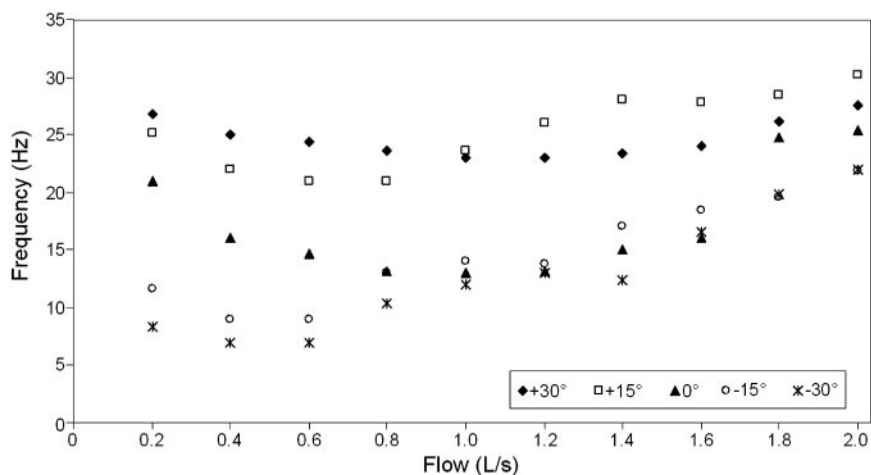


Fig. 5. Mean frequency developed by the Flutter VRP1 at all angles and all flow rates. Each point represents a mean of 5 values of frequency. There were statistically significant differences between all values of frequency ($p < 0.01$). The angles of $+30^\circ$ and $+15^\circ$ produced higher frequency values ($p < 0.01$), whereas the lower values were produced at -30° and -15° at all flows ($p < 0.01$).

which device inclination and supplied flows change the physical variables of the device (mean pressure, mean flow, oscillation frequency, and flow amplitude), which consequently influence the effects on airway clearance. Table 1 presents a comprehensive summary of the most important findings from the present study by showing the relationship among physical variables, airway clearance effects, and theoretical best conditions of expiratory flow and inclination, in order to facilitate the device effects.

Obviously, a study with all possible angles and flows involved in the Flutter VRP1 therapy would not be feasible. Thus, the angle and flow values included in the present study aim at providing as much useful information as possible and were defined based on the clinical experience with the device. Flows up to 2.0 L/s are fully possible to

be generated by individuals who have no severe expiratory flow limitation. Previous studies used equipment with continuous production of low flows (mechanical ventilators or air compressed systems) aiming at studying the performance of the Flutter VRP1,^{4,13,16} with the exception of a study¹ that used up to 3.5 L/s, and another that used up to 6.0 L/s.¹³ The instructions for use of the device are clear concerning the utilization of minimum amounts of effort and, therefore, lower flows. However, this strategy limits the evaluation of the whole range of its effects on airway clearance.

Other methodological considerations involving the present study regard the way of applying air flow. This study used a system of constant flow source, since the objective was to investigate the device behavior at differ-

PERFORMANCE ANALYSIS OF THE FLUTTER VRP1

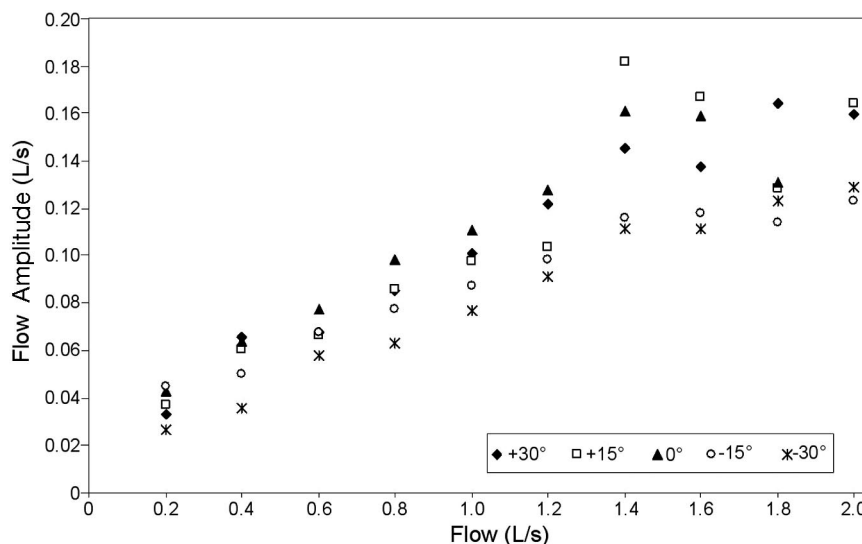


Fig. 6. Mean flow amplitude developed by the Flutter VRP1 at all angles and all flow rates. Each point represents a mean of 5 values of flow amplitude. There were statistically significant differences between all values of flow amplitude ($p < 0.01$). The angles of +15° and +30° produced higher flow amplitude values ($p < 0.01$) at higher flow rates, whereas the lower values were produced at -30° and -15° at lower flows ($p < 0.01$).

Table 1. Summary of the Relationship Between the Device Physical Variables, Airway Clearance Effects, and Theoretical Best Conditions of Expiratory Flow and Inclination to Optimize the Device Effects

Physical Variable	Airway Clearance Effect	Best Expiratory Flow	Best Inclination
Mean flow	Huff	Lower flows and lower lung volumes for secretions in distal airways	-30°
		Higher flows and higher lung volumes for secretions in proximal airways	+30°
Mean pressure	Positive expiratory pressure (PEP)	0.2 L/s at PEP of 10 cm H ₂ O and above 1.0 L/s at PEP of 20 cm H ₂ O	+15°/+30°
Oscillation frequency	High-frequency airway oscillation	≥ 0.2 L/s	All except -30°
Flow amplitude	Flow amplitude	> 1.4 L/s	0°/+15°/+30°

ent flow values, and this behavior can be replicated as described in previous studies.^{1,12,13} However, it is known that the expiratory flow decreases progressively in the Flutter VRP1 operation.¹¹ Therefore, in clinical practice, the device operational conditions can change from the beginning to the end of the maneuver, so the device's optimized effect on airway clearance can also differ throughout the expiratory maneuver.

As the Flutter VRP1 maintains a positive pressure in the airways during the whole expiratory phase, it promotes a technique of respiratory physiotherapy called PEP. PEP effect is used to prevent airway closure,² and its production depends, fundamentally, on the resistance of the device. The higher the resistance, the higher the PEP obtained with lower flow requirement. In the Flutter VRP1, the airflow resistance depends on the inclination (angle) of the device and the supplied flow, which are factors that change the position of the steel ball above the conical seat,

facilitating or hindering the air flow. At the inclination of +30° and above 1.6 L/s the ball is positioned entirely outside of the conical seat, practically without horizontal movement and without colliding against the seat¹³ (a condition that can determine a lower resistance to air flow). It is also supposed that at other inclinations and flows the settlement and the shocks of the steel ball are nearly constant, defining the variability of the resistance values.

According to Figure 4, the best values of mean resistance were obtained with positive inclinations at all flows, whereas the lower values were obtained at -30° and at lower flows (up to 0.6 L/s). Therefore, it seems clear that in order to optimize the PEP effect, the device should be positioned in positive inclination, which facilitates reaching adequate pressure values by individuals with airflow limitation. Values of PEP between 10 and 20 cm H₂O, but mainly above 20 cm H₂O, have been suggested to determine more effectiveness in airway clearance in subjects

with cystic fibrosis,¹⁴ although the ideal value should be individualized.¹⁷ In all tested inclinations it was possible to reach mean pressure between 10 and 20 cm H₂O. However, +30° (mean pressure of 10 cm H₂O) and +15° (mean pressure of 20 cm H₂O) were the inclinations that produced values of mean pressure with lower flows, which favors the use of these inclinations by individuals with airflow limitation.

In theory, huff performed with lower flow and with lower lung volume prevents excessive dynamic airway compression and promotes mobilization of the mucus located more in the periphery of the bronchial tree, whereas with high flows and high lung volumes the effect is more pronounced in the proximal airways.^{18,19} Lower flows are reached with a minimum amount of effort and with any inclination of the device, particularly -30°. However, high flows are favored in some inclinations, as a consequence of the alteration of the device resistance due to the positioning of the steel ball in the conical seat. As shown in Figure 4, with flows between 0.8 L/s and 1.6 L/s the lower values of mean resistance were obtained at 0°, and above 1.8 L/s at +30° of inclination. This possibly happens as a consequence of the elevation of the steel ball outside of the seat in these conditions, which would allow the air flow to happen in a less turbulent manner. Therefore, the use of the device to favor huff effect should consider the location of the secretions (ie, based on lung auscultation) in order to define the adequate flow rate in each situation, although it is not usual to use the device with high flows. When used by subjects with expiratory muscle weakness, it is also important to take into consideration their peak expiratory pressure (indicative of expiratory muscle strength) in order to choose the inclination that allows the user to reach the desired flow with a tolerable effort.

The ideal frequency of the intrabronchial vibration (or oscillation) waves generated by the device is above 12 Hz,¹⁵ and the maintenance of that oscillation for as long as possible increased the effects on the mucus rheology in *in vitro* studies.^{5,20} The higher the applied frequency (until 22 Hz), the greater the reduction in viscoelasticity.²¹ Therefore, the ideal behavior would be that the device reaches 12 Hz frequency with the lowest expiratory flow, which would favor patients with airflow limitation. Figure 5 shows that positioning the device in positive and neutral inclinations would favor this behavior and optimize the high-frequency airway oscillation effect because it allows obtaining the ideal frequency with lower flows and a longer expiratory time. On the other hand, when at -30°, only with intermediate to high flows was it possible to obtain the frequency of 12 Hz, which may hinder the effectiveness of the device in this position when used by subjects with airflow limitation.

The oscillation of the steel ball generates peaks of intermittent expiratory flow that can be responsible for pro-

moting micro-movements of the mucus in the direction of the upper airways.^{1,4,5} Therefore, the higher the flow amplitude, the higher the effectiveness of the therapy. Equally important is that the higher amplitude is obtained with the least possible effort of pressure or flow. According to Figure 6, positive and neutral inclinations produced higher values of flow amplitude, although with the need for higher flow (above 1.4 L/s) to reach these higher flow amplitude values. This means that higher effectiveness in terms of flow amplitude requires the generation of higher expiratory flows. Once again, this may limit the effects of the device in patients incapable of generating such higher flows.

Conclusions

According to the present study there is a clear influence of different angles of inclination and expiratory flows in the performance of the Flutter VRP1, and its effects on the mobilization of bronchial mucus can be optimized in these conditions: PEP, high-frequency airway oscillation, and flow amplitude effects from positive inclinations, and huff effect from negative inclinations. Since there are no available studies in which the device was prescribed in clinical practice taking into account these influences, the present results require confirmation in clinical studies. However, we believe that the effects of the device in clinical practice could be optimized by an individualized prescription that takes into consideration each situation and subject, aiming to focus on one or more of these effects. Although based on experimental data, the facts summarized in Table 1 may guide future research and clinical practice in order to define more precisely the indications and best ways to use the device when applied to different pathological conditions.

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