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Laboratory evaluation of four different devices for secretion mobilisation: Acapella® Choice, green and blue versus water bottle

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Abstract

Background: Secretion removal is a key issue in patients with respiratory diseases and known to be most effective at vibration frequencies around 13 Hz and with the greatest amplitudes possible. The Acapella® devices and the water bottle are used for secretion removal in daily clinical practice but without detailed knowledge on optimal settings. The aim of this study was to evaluate the three different Acapella® devices and the water bottle at various settings and flows to determine the optimal device(s) and setting(s) for effective secretion removal.

Methods: Three different Acapella® devices were tested at flows of 6, 12, 20, 30, 40 and 50 L/min and at all five settings. The water bottle was filled with 5, 10 or 15 cm of water and tested at flows of 3, 6, 10, 12 and 20 L/min. For all devices and combinations of settings, we measured the frequency and amplitude of the vibrations as well as the required pressure to generate vibrations.

Results: Setting 4 was the best for all three Acapella devices, and the filling height of the water bottle should be 5 cm. At these settings all devices elicited vibration frequencies between 12 and 15 Hz which is theoretically optimal for secretion mobilization. The resistance pressures of the devices to elicit these vibrations were between 5 and 11 cmH_2O. However, the Acapella devices elicit higher vibration amplitudes (5 to 8 cmH_2O) than the water bottle (1.8 cmH_2O)

Conclusion: Setting 4 was optimal for all three Acapella® devices. The Acapella® devices may be more efficient for secretion mobilization than the water bottle, because they elicit greater amplitude of vibrations.

Key words: airway clearance therapy, bronchial clearance, chest physiotherapy, evaluation of devices, mucus, oscillating positive expiratory pressure, respiratory secretions

Word count: 267

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Introduction

Secretion clearance is of utmost importance in conditions with excessive production of sputum (e.g. cystic fibrosis) or secretion retention as a result of weak or paralyzed respiratory muscles (e.g. multiple sclerosis, amyotrophic lateral sclerosis, spinal cord injury). There are different devices for secretion mobilization (e.g. Flutter®, Acapella®, water bottle or chest vibration vests) with various requirements for their successful use. In order to use the devices effectively, it is very important to know specific requirements e.g. the required expiratory pressures and flows and also the device's or setting's specific vibration frequencies and amplitudes. The applied vibration frequency is most effective for secretion mobilization when it matches the frequency of the ciliary movement, which is approximately 13 Hz. [1] Furthermore, the greater the amplitude of the vibrating air, the better is the effectiveness of the therapy.[2] Although these parameters are critical for the effective use of a device for secretion mobilization, it is uncommon to find this information in the user manuals of the devices.

In some studies the vibration frequency and amplitude of the Flutter® [2, 3] and the Acapella® [3-5] devices have been evaluated at different settings. However, only two of the three different Acapella® devices (blue, green and Choice) have been evaluated in the above mentioned studies. There is no literature on the characteristics of the Acapella Choice® device, and not all of the five settings of the 'green' and the 'blue' Acapella® devices have been investigated.[3]

The water bottle is a very cheap and readily available tool for secretion mobilization and is often used in clinical practice. The only things needed are a 1.5 L plastic bottle filled with some water and a flexible tube. If it was effective, the water bottle would also be an interesting tool in developing countries with limited financial resources and limited access to devices such as the Flutter® or the Acapella®. However, the settings for effective secretion

mobilization, i.e. water quantity, flow rates and tube positioning for producing frequencies around 13 Hz with great amplitude oscillations, are not known.

There is a general agreement in the literature, that it is necessary to perform new studies evaluating oscillatory devices for secretion mobilization. [2-4, 6, 7] Therefore, the aim of this laboratory evaluation was to determine the optimal settings for the three Acapella® devices as well as for the water bottle, for reaching oscillating frequencies around 13 Hz with the greatest possible amplitudes.

Methods

Acapella®

The Acapella® devices (DHD Healthcare, Wampsville, New York) combine high-frequency oscillation and positive expiratory pressure by employing a counterweighted lever and magnet. [3] Exhaled air passes through a cone, which is intermittently occluded by a plug attached to the lever, producing air flow oscillations. All three devices have five different settings, which can be selected by turning a wheel at the distal end of the device. This changes the proximity of the magnet and counterweighted plug, thereby adjusting the vibration frequency and amplitude as well as the required mean pressure. [3] The three different models are described as follows on the manufacturer's homepage: Acapella Choice®: autoclave-able, for all patients, Acapella blue® for expiratory flows of <15 L/min (for three seconds) and Acapella green® for expiratory flows of >15 L/min (for three seconds).

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Water bottle

The water bottle as used in this study, was a 1.5 L plastic bottle (conventional beverage bottle) with a medical grade PVC tube of 50-60 cm length and an inner diameter of 8 mm. The bottle can be filled with different water volumes depending on the expiratory muscle strength of a patient. The required expiratory pressure increases with increasing water volumes.

Measurement set-up and data acquisition

All devices were connected to a gas flow and pressure analyzer (VT plus, BIO-TEK, Fluke Biomedical, USA) and an adjustable constant air flow (Figure 1). All three Acapella® devices were tested in a horizontal position at flows of 6, 12, 20, 30, 40 and 50 l/min and at all five settings. The flow rates for testing the Acapella® devices were chosen according to values used in clinical practice or published in the literature. [4] Even though the Acapella® devices are specified for different flow rates (model green > 15 L/min, model blue < 15 L/min), we tested all devices at all flow rates, in order to have a direct comparison between the devices. The water bottle (1.5 L plastic bottle) was filled to a water height of 5, 10 or 15 cm and tested at flow rates of 3, 6, 10, 12 and 20 L/min because this device is usually used for patients with highly impaired expiratory function.

First, we determined the resistance of every measurement set-up, i.e. the gas flow analyzer and the tube with the connected device. The resistance of the measurement set-up was detracted from the measured resistance of each tested setting. The sampling frequency was 50 Hz, and for each test setting, 30 s of data was recorded and stored locally. We measured the frequency [Hz] and amplitude [cmH_2O] of the oscillating air as well as the resulting pressure [cmH_2O] to generate the oscillation for all tested settings.

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Analysis

The data stored locally in the gas flow analyzer were exported to a personal computer and stored as ASCII files. Further data processing of the ASCII files was performed with MatLab7 (MathWorks, Natick, Massachusetts, U.S.A.). In order to have stable values, the data recorded between the 15th and the 20th second were used for further analysis. The means of the data recorded between the 15th and 20th second were calculated and used for creating the figures. The frequencies of the oscillating air were calculated with a Fourier transformation using MatLab7. Flow, pressure and amplitude data for each device and for all tested settings were also exported from the gas flow analyzer to MatLab. We generated figures of amplitudes, frequencies and pressures vs. flow for each device at all tested settings using Systat 10.2 (Systat Software Inc., Chicago, IL , USA). For determining the optimal settings (Acapella®) or filling height (water bottle), we first selected oscillating air frequencies which were between 11 and 15 Hz (13 ± 2 Hz). Secondly, settings and flows corresponding to these frequencies were identified. Finally, the corresponding amplitudes of these settings and flows were analyzed. The optimal setting or filling height was determined by the flow generating the vibration frequency with the greatest amplitude within the target frequency range. Furthermore, the required pressure for generating this flow was identified.

Results

Acapella®

The required expiratory pressure to generate vibrations increased more with higher flow rates than with increasing settings of the Acapella® devices (Table 1).

The frequency-flow relationship of the Acapella blue® device (Figure 2a) showed an inverse pattern compared to the Acapella Choice® (Figure 2b) and the Acapella green® device (Figure 2c). Even though the amplitudes of the vibrating air did not show a clear pattern, the Acapella

blue® (Figure 3a) produced lower amplitudes compared to the Acapella Choice® (Figure 3b) and the Acapella green® (Figure 3c).

Water bottle

Increasing the filling height of the water bottle increased the required pressure to generate a vibrating effect (filling height = required pressure in cmH_2O), under the condition that the end of the tube was at the bottom of the bottle. Clear vibration signals resulted only if the end of the rubber tube was in the proximity of the bottle wall and not if it was in the middle of the bottle. We recorded vibration frequencies in the target range (13 ± 2 Hz) with a filling height of 5 cm and at a flow of > 6 L/min (Figure 4a). Unfortunately, all vibration amplitudes were much lower compared to the Acapella® devices (Figure 4b).

The optimal settings for the four tested devices are presented in Table 2.

Discussion

This study shows, that the Acapella green® device generates the greatest amplitudes in the optimal frequency range. To our knowledge, there are only two other studies in which the Acapella® devices have been evaluated concerning the optimal settings for generating vibrations effective for secretion mobilization. [3, 4] Volosko et al. [3] have only tested the Acapella blue® device at low flow rates of 5-15 L/min and the Acapella green® device at high flow rates of 20-30 L/min. Furthermore, they have only evaluated settings 1, 3 and 5. Nevertheless, the mean pressures, amplitudes and frequencies, which they have reported, are comparable to our results. In another study[4], the Acapella green® device has been evaluated at all five settings for flow rates (12-48 L/min) comparable to the present study. However, only the physical performance has been investigated.[4] The reported frequencies, pressures and amplitudes were in a similar range as our results, but the differences in pressure and

amplitude between the five settings were smaller. [4] Alves Silva et al. [4] have used three different Acapella green® devices and calculated the means of the measured values which may have smoothened the curves and resulted in the discrepancies with the present results. Two further studies have compared the Acapella® device (model not specified) with normal airway clearance in clinical crossover trials. [1,5] These papers have a high clinical relevance, because they have assessed the expectorated sputum volumes. However, the Acapella® device settings have not been reported, and it is therefore difficult to compare these results with ours. We are the first to evaluate the Acapella Choice® device, which has the advantage that it can be sterilized. However, in the light of our results, the usefulness of the Acapella Choice® is questionable, because it produces vibrations with higher frequencies and smaller amplitudes than the Acapella green device which are less optimal for secretion mobilization (Table 2) and it has the same pressure and flow requirements as the Acapella green® device.

Another important factor for determining optimal settings for secretion mobilization devices is the natural frequency of the chest, pulmonary tissue and the respiratory tract. [8] Cegla and Retzow have reported that natural lung-chest frequencies vary between 12 and 15 Hz. [9] According to de Lima et al. [8] the natural frequency also depends on the postural position (i.e. sitting or standing) and is lower in patients with respiratory illness like e.g. cystic fibrosis. The literature on this topic is very sparse and mainly supports frequencies in the target range chosen in our study (i.e. 11-15 Hz). [1, 8, 9]

We have also evaluated the vibration properties of the water bottle, because this is a tool often used in clinical practice, by patients at home, and it is cheap and easily obtainable. However, an increased infection risk may develop if the water is not changed daily, and if the bottle as well as the tube are not exchanged regularly. To our knowledge, no literature exists concerning the optimal settings of the water bottle. Like the Acapella® devices, the water bottle can be used at different settings (e.g. filling height, flow rates, placement of the tube)

and the evaluation of the optimal settings is therefore justified. Our results clearly demonstrate, that the water bottle may not be effective in all patients, because it generates only very small amplitudes at which optimal secretion mobilization is questionable. However, the water bottle has the advantage, that it can be used with a water height of only 5 cm which requires a very low expiratory muscle strength and is therefore suitable for patients who are not yet able to use the Acapella blue® device. The water bottle may also be an interesting, cheap option in developing countries, if basic hygienic principles are followed and access to clean water is ensured.

We suggest the following approach for the clinical application of these devices: Acapella green® seems to be the best device when patients are able to sustain a minimal expiratory pressure of 11 cmH_2O with a flow of 30 L/min for at least three seconds. The Acapella blue® device may be optimal for weaker patients who are able to generate expiratory pressures of 8-10 cmH_2O at flow rates of only 12 L/min. Interestingly, all Acapella® devices show their best vibration characteristics at setting 4. Even though the vibration amplitude of the water bottle is rather small, it may be used in very weak patients with expiratory pressures of only 5-7 cmH_2O, in order to start a therapy for secretion mobilization as early as possible.

Limitations

The limitations of this study are that the present measurements have been made in a laboratory setting, and the results are therefore theoretical optimal settings, which have to be confirmed in patients in a clinical setting. However, this was the first step in the evaluation of the optimal device settings. Furthermore, the optimal frequency and intensity of the therapy are still unknown, and the response of individual patients may vary at different flows and amplitudes depending on the degree of airflow obstruction and/or disease specification and severity. Concerning the water bottle, we did not investigate and determine the optimal size of the bottle and the length and placement of the tube. Nevertheless, the required pressure is only

234 determined by the water filling height and thus the size of the bottle does not seem to play an
235 important role.
236
237 **Conclusion**
238 The Acapella® devices seem to be more efficient for secretion mobilization than the water
239 bottle, because they generate greater vibration amplitudes. We suggest the use of the
240 Acapella green® device as soon as patients are able to sustain a minimal pressure of 11
241 cmH_2O with a flow of 30 L/min for at least three seconds. Generally, all three Acapella®
242 devices should be used at setting 4, because frequencies and vibration amplitudes are only
243 optimal at this setting.
244
245 **Acknowledgement**
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248
249 **Literature**
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Figure legends:

Figure 1:

Measurement set-up: Gas flow analyzer connected to an Acapella® device

1 = gas cock

2 = connecting tube (8 mm inner diameter) from gas cock to analyzer (gas with known flow rate)

3 = gas flow and pressure analyzer

4 = connecting tube (8 mm inner diameter) from analyzer to Acapella® device (gas with known flow rate)

5 = Acapella® device

6 = connecting tube (4 mm inner diameter) from the Acapella® device to analyzer, to measure vibration frequencies, pressures and amplitudes of the vibrating air in the Acapella® device.

Figure 2a-2c:

Frequency-flow relationship at the five different settings and for all three Acapella® devices (2a: Acapella® blue; 2b: Acapella® Choice; 2c: Acapella® green); please note that in Figure 2a and Figure 2b parts of setting 2, 3 and 4 overlay with other settings and in Figure 2c setting 2 and 3 are completely overlaying with setting 1 (Reported values are means over the analyzed time period at each setting and flow rate.)

Figure 3a-3c:

Amplitude-flow relationship at the five different settings and for all three Acapella® devices (3a: Acapella® blue; 3b: Acapella® Choice; 3c: Acapella® green). Note that reported values are means over the analyzed time period at each setting and flow rate.

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Figure 4a/4b:

Frequency-flow relationship (4a) and amplitude-flow relationship (4b) of the water bottle at all three filling heights [cm]. Note that reported values are means over the analyzed time period at each filling height and flow rate

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Table 1: Required pressures (range of means over the measured time period of the five different settings) of the three Acapella® devices to generate different flows.

	Acapella Choice®	**Acapella green®**	**Acapella blue®**
Flow [l/min]		pressure [cmH_2O]	
6	2-7	2-7	1-8
12	2-7	4-7	8-10
20	5-8	5-8	10-15
30	10-12	7-12	22-30
40	16-20	15-20	42-58
50	27-30	21-27	100-120

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Table 2: Optimal settings for the Acapella® devices and optimal water filling height for the water bottle (pressures, frequencies and amplitudes are means over the measured time period).

Device	Setting/Filling Height [cm]	Flow [l/min]	Pressure [cmH_2O]	Frequency [Hz]	Amplitude [cmH_2O]
Acapella Choice®	4	30	11	15	8
Acapella blue®	4	12	8	13	5
Acapella green®	4	30	11	13	6
Water bottle	5	12	5	12	1.8

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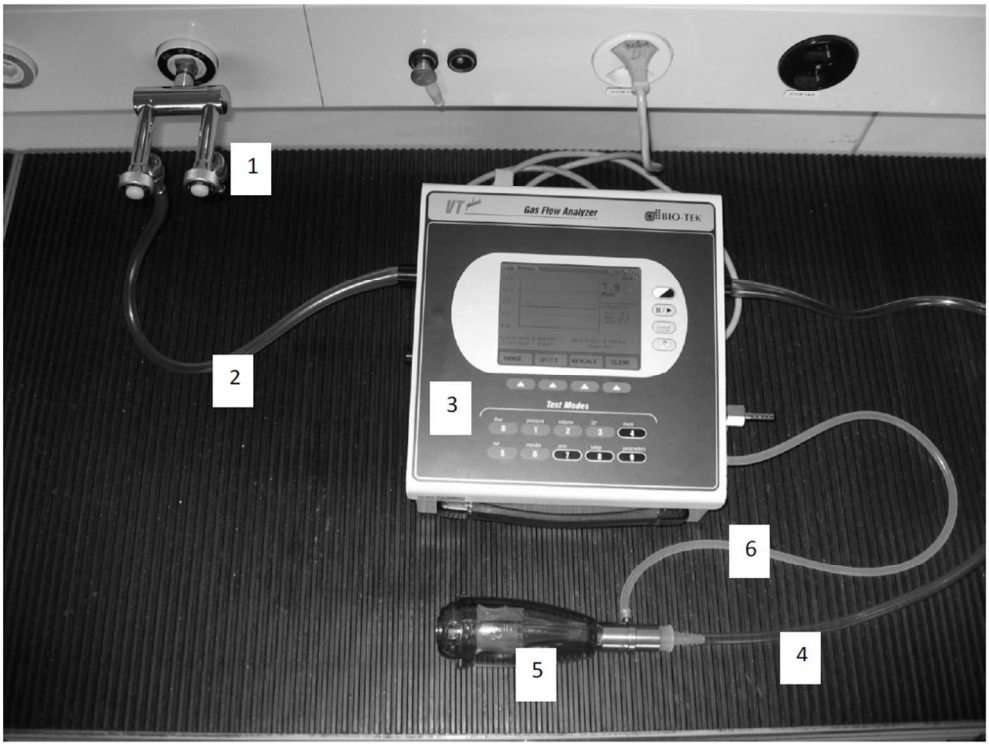

Measurement set-up: Gas flow analyzer connected to an Acapella® device
1 = gas cock
2 = connecting tube from gas cock to analyzer (gas with known flow rate)
3 = gas flow and pressure analyzer
4 = connecting tube from analyzer to Acapella® device (gas with known flow rate)
5 = Acapella® device
6 = connecting tube from the Acapella® device to analyzer, to measure vibration frequencies, pressures and amplitudes of the vibrating air in the Acapella® device.

374x282mm (72 x 72 DPI)

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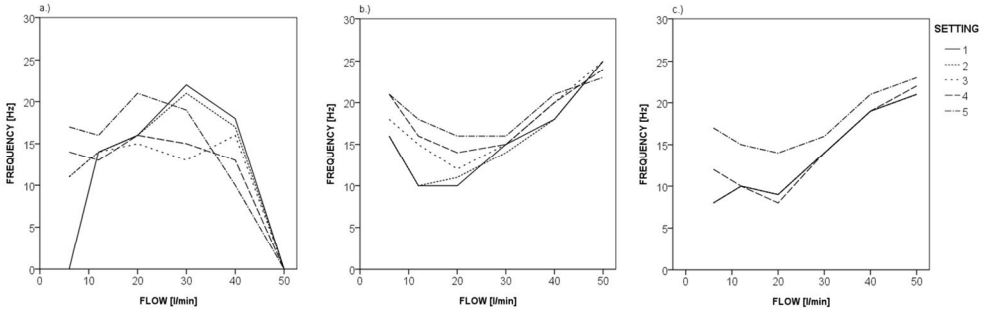

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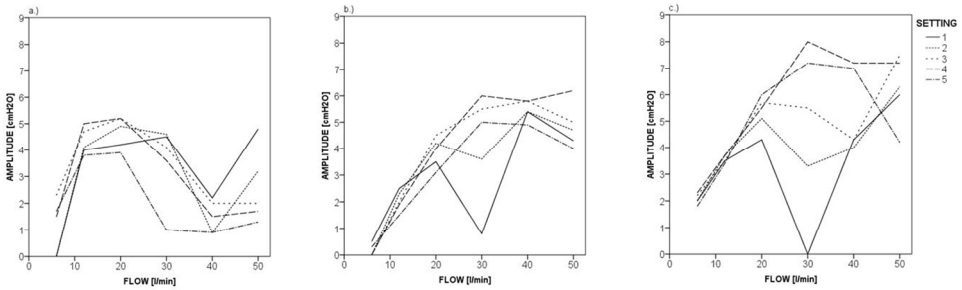

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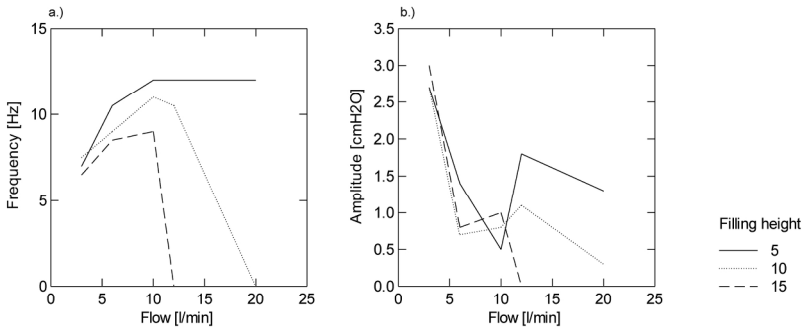
Figure 4



Frequency-flow relationship (4a) and amplitude-flow relationship (4b) of the water bottle at all three filling heights [cm].
209x148mm (300 x 300 DPI)