Performance Characteristics of Positive Expiratory Pressure Devices

Angela M Demchuk and Robert L Chatburn

BACKGROUND: Positive expiratory pressure (PEP) therapy imposes expiratory flow resistance to increase airway diameter and enhance mucus clearance. PEP is achieved several ways. Oscillatory PEP devices (OPEP) generate repeated occlusions that are known to reduce mucus viscosity. There are many marketed devices, but comparative performance is mostly unreported. The purpose of this study was to evaluate performance characteristics of many PEP/OPEP devices. For OPEP devices, we defined an optimal performance metric by creating an oscillation index that combines the OPEP performance characteristics. METHODS: PEP devices (TheraPEP, EzPAP, VersaPAP, Resistex, AccuPEP, AccuPAP, and Threshold PEP) and OPEP devices (Acapella DH, Acapella DM, Acapella Choice, ShurClear, Aerobika, VibraPEP, vPEP, and PocketPEP with and without the Oxyjet attachment) were tested by adjusting simulated expiratory flow from 5 L/min to 30 L/min in increments of 5 L/min using a standard flow meter. RESULTS: All devices showed varying performance characteristics. As expiratory flow increased, mean PEP increased for most devices. The TheraPEP showed a mean PEP of 13 cm H_2O across all settings. For OPEP devices, there was a major difference between pressure and flow waveforms. The Acapella DH, ShurClear, and Aerobika showed the highest flow amplitude, flow frequency, and oscillation index. CONCLUSIONS: PEP devices behaved similarly and as expected, with increased pressure with increased flow (flow resistors) or flow independence (threshold resistors). There was much greater variation in the performance of the OPEP devices. A higher oscillation index indicates better mechanical performance characteristics. Many devices have similar characteristics. However, the devices with the highest oscillation index have the highest flow amplitude and frequency, which may indicate better clinical performance. *Key words: positive expiratory pressure; oscillatory positive expiratory pressure devices; respiratory device evaluation.* [Respir Care 2021;66(3):482–493.

Introduction

Airway clearance techniques are therapies used to help patients move and expel secretions. One type of airway clearance technique is positive expiratory pressure (PEP) therapy, which uses imposed expiratory flow resistance to generate airway pressure above atmospheric pressure. This airway pressure presumably increases airway diameter and improves expiratory flow behind the mucus, allowing it to be loosened and expelled more easily. Patients who use PEP therapy must be able to produce a controlled, prolonged exhalation to provide enough expiratory flow for the therapy to be useful. PEP therapy allows for enhanced mucociliary clearance, which improves patients' quality of life.[1]

There are many different designs of PEP devices, and they generate PEP in 3 different ways. The simplest method of generating PEP is using a flow resistor, such as an orifice (ie, the smaller the diameter, the higher the imposed resistance). The generated pressure is "controlled" by the patient's expiratory flow and may be monitored by a simple pressure gauge. Another method is a threshold resistor, which is a device such as a spring or magnet that generates a force for flow obstruction that allows flow only when PEP reaches the requisite threshold level. This permits calibration of the obstructing force mechanism (ie, desired PEP level) and obviates the need for a pressure-monitoring device. A third method is to use an external flow source to

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oppose the expiratory flow and thus generate PEP. Some devices use a combination of mechanisms (eg, threshold resistor plus opposing flow).

Oscillatory PEP (OPEP) devices use mechanisms to create a series of short occlusions of expiratory flow to generate oscillatory airway pressure and flow waveforms. Studies have reported that the oscillation of expiratory flow causes changes in the viscosity of mucus[2] and shear forces that increase mucus clearance.[3]

The clinical efficacy of PEP therapy has recently been reviewed.[4] However, there is limited information about the technical performance of PEP devices themselves.[5-8] Of particular interest is a recent study by Poncin et al[9] comparing 6 OPEP devices (some not available in the United States). They noted that OPEP often produces 2 main salutary physiologic effects: (1) PEP to stabilize the airways and prevent collapse during expiration,[10] and (2) air-flow oscillations to facilitate mucociliary clearance.[2,11] Importantly, their analysis of the literature was the first to suggest that an optimal OPEP device should be able to produce flow oscillations with a frequency of at least 12 Hz and an expiratory pressure of at least 10 cm H_2O. Their results summarized 24 simulated exhalations through 6 OPEP devices and quantified the expected variable performance among the devices (eg, pressures, flow amplitude, and frequency).

The purpose of our study was to expand the work of Poncin et al[9] by evaluating a larger number of both PEP and OPEP devices. Our goal was to describe the relationship between flow through the devices and the resulting mean pressure. This is important because many studies of OPEP devices have not recorded flow characteristics, which are more relevant than pressure characteristics in creating a clinical effect on mucus clearance. Therefore, we sought to specifically evaluate OPEP devices in terms of oscillatory flow amplitude and frequency. In addition, we expanded on the idea of an "optimal" performance metric by creating an oscillation index that combines the salutary physiologic OPEP mechanical properties of oscillatory flow amplitude and oscillatory frequency.

QUICK LOOK

Current knowledge

Positive expiratory pressure (PEP) devices are used as a form of airway clearance therapy to increase airway diameter and enhance mucus removal. There are many devices available, and studies have been done to analyze performance characteristics.

What this paper contributes to our knowledge

This study extends current knowledge by providing data on a large number of PEP and oscillatory PEP devices and by focusing on flow frequency and flow amplitude as important performance characteristics. Furthermore, an oscillation index was created to allow the mechanical aspects of oscillatory PEP devices to be easily compared.

Methods

Experimental Setup

The devices used in this study are listed in Table 1. The experimental setup is shown in Figure 1. The simulated exhaled flow and external PEP flow source (ie, the flow opposing expiratory flow if applicable to the device) were controlled with standard medical air-flow meters connected to an air compressor. The pressure and flow through the devices were measured with a pneumotachometer amplifier (series 1110) and a pneumotachometer (0–160 L/min) with a flat frequency response up to 20 Hz (Hans Rudolph, Shawnee, Kansas). Data were recorded at a sampling rate of 1,000 Hz. A digital low-pass filter with a cutoff frequency of 60 Hz on the flow channel and 45 Hz on the pressure channel was used to minimize noise and stay within the range of the pneumotachometer. The analog-to-digital converter was a PowerLab/30 Series from ADInstruments, and the signal analysis software was LabChart 8 (ADInstruments, Colorado Springs, Colorado).

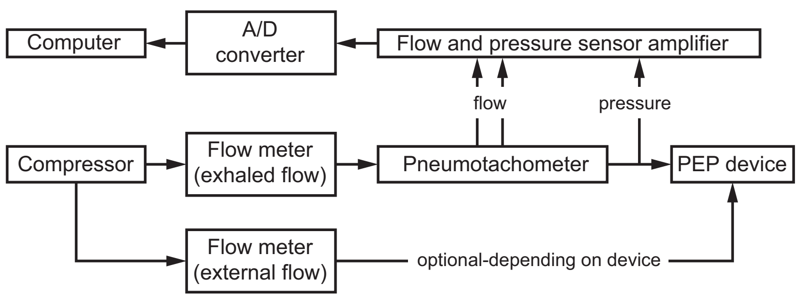

Fig. 1. Experimental setup. A/D = analog to digital; PEP = positive expiratory pressure.

Table 1. Devices Studied

Name	Manufacturer	Type	Mechanism	Settings	Range
TheraPEP	Smiths Medical, Minneapolis, MN	PEP	Flow resistor	1–6	13 cm H_2O
Resistex	Mercury Medical, Clearwater, FL	PEP	Flow resistor	1–4	5–20 cm H_2O
Threshold PEP	Phillips Respironics, Chichester, UK	PEP	Threshold resistor	Twist 5–20 cm H_2O	5–20 cm H_2O
AccuPEP	Sarnova, Dublin, Ohio	PEP	Threshold resistor	1–4	5–20 cm H_2O
AccuPAP	Sarnova, Dublin, Ohio	PEP	Threshold resistor with external flow	1–4	5–20 cm H_2O
EzPAP	Smiths Medical, Minneapolis, MN	PEP	Threshold resistor with external flow	NA	5–20 cm H_2O
Versa PAP	Monaghan Medical, Plattsburgh, NY	PEP	Threshold resistor with external flow	NA	5–20 cm H_2O
Oxyjet	D R Burton Healthcare, Farmville, NC	PEP	Threshold resistor with external flow	NA	5–20 cm H_2O
Acapella DH	Smiths Medical, Minneapolis, MN	OPEP	Intermittent occlusion	1–5	5–20 cm H_2O
Acapella DM	Smiths Medical, Minneapolis, MN	OPEP	Intermittent occlusion	1–5	5–20 cm H_2O
Acapella Choice	Smiths Medical, Minneapolis, MN	OPEP	Intermittent occlusion	1–5	5–20 cm H_2O
VibraPEP	Sarnova, Dublin, Ohio	OPEP	Intermittent occlusion	1–5	5–20 cm H_2O
Aerobika	Monaghan Medical, Plattsburgh, NY	OPEP	Intermittent occlusion	1–5	5–20 cm H_2O
vPEP	D R Burton Healthcare, Farmville, NC	OPEP	Intermittent occlusion	Dial	5–20 cm H_2O
ShurClear	Mercury Medical, Clearwater, FL	OPEP	Intermittent occlusion	Angle	6–20 Hz
PocketPEP	D R Burton Healthcare, Farmville, NC	OPEP	Intermittent occlusion	Flip	5–20 cm H_2O

PEP = positive expiratory pressure
NA = not applicable
OPEP = oscillatory positive expiratory pressure

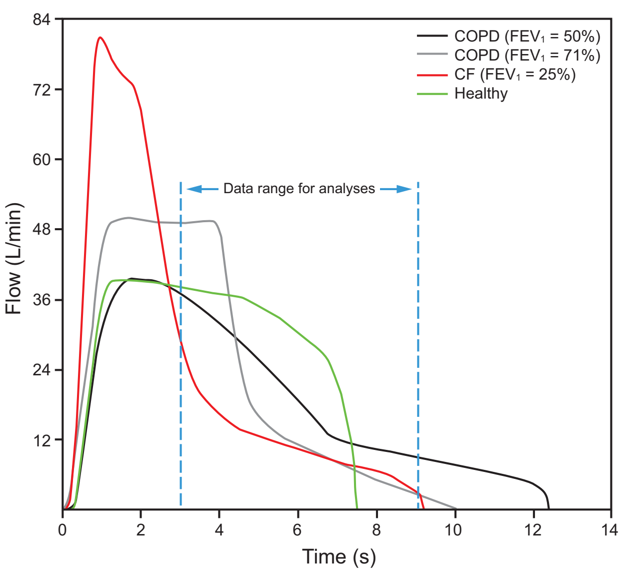

Fig. 2. Simulated patient expiratory flows used in the study by Poncin et al.[9] CF = cystic fibrosis.

Device Settings

All of the devices, except the EzPAP, Oxyjet, and VersaPAP, have a range of settings on the device that increase or decrease the pressure against the simulated expiratory flow. PEP for the EzPAP, Oxyjet and VersaPAP was adjusted using external flow only (Table 1). For PEP and OPEP devices, the lowest and highest device settings were used during the experiments. PEP for EzPAP and Oxyjet devices was adjusted by setting the external flow. The Oxyjet was not tested alone because it is intended to be used as an attachment to other PEP devices to provide supplemental oxygen and increased mean PEP.

Procedure

Before taking measurements, the pressure and flow sensors were calibrated. Expiration through the PEP devices was simulated as a constant flow, adjusted from 5 L/min to 30 L/min in increments of 5 L/min, with the exception of the Acapella DM because it is designed for flows ≤ 15 L/min. This flow range was selected to be consistent with previous studies.[5-8,10,12,13] In particular, this flow range is within the range used by Poncin et al,[9] who based them on actual patient data (Fig. 2).

The TheraPEP device is unique in that it uses both flow resistance and biofeedback. The pressure is created by resistance to flow through an orifice, but the device incorporates an uncalibrated pressure gauge. The gauge has 2 reference marks on the outer case, and the patient is instructed to regulate exhalation such that the pressure (indicated by a third mark on an inner piston) stays between the 2 reference marks. According to the directions, upon exhalation, the patient should try to keep the PEP level in the optimal range indicated by the marks. This device allows the clinician to adjust the setting based on the patient's ability to control expiratory flow. Hence, for the

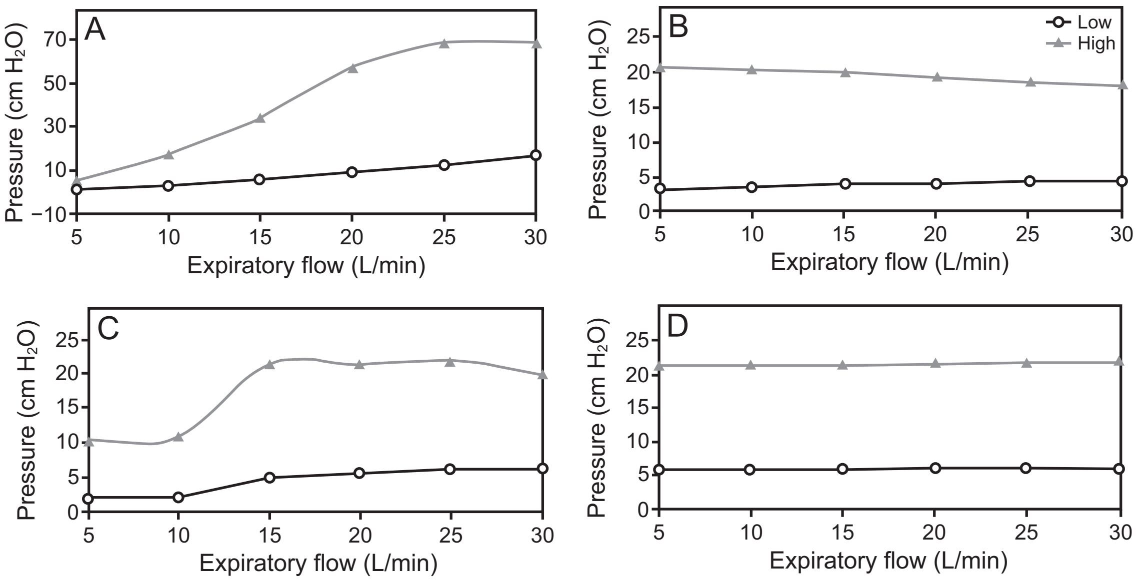

Fig. 3. Data for positive expiratory pressure devices using flow or threshold resistance. Note that the AccuPAP can be used with an optional external flow source at 10 L/min (as used in the study). A = Resistex, B = AccuPEP, C = Threshold PEP, D = AccuPAP.

study, simulated expiratory flows were adjusted empirically to maintain PEP between the marks.

The EzPAP and the VersaPAP also required a different protocol because it was unclear what pressure was generated at each setting. Guidelines suggest a mean PEP of 10–20 cm H_2O. In accordance with the device instructions, external flows were set at 6, 8, 10, and 12 L/min for the VersaPAP and at 4, 6, 8, and 10 L/min for the EzPEP. Pressure data were collected at each simulated expiratory flow setting. Each device was tested twice to ensure results were replicable.

Data Analysis

Mean airway pressure (reported as mean PEP), oscillatory flow frequency, and oscillatory flow amplitude were recorded as calculated by the signal analysis software. These metrics were averaged over at least 10 cycles for OPEP devices. Average values from the 2 experimental runs per device were calculated and graphed in a spreadsheet. Representative pressure and flow waveforms (recorded by the signal analysis software) were recorded for each device at a simulated expiratory flow of 15 L/min.

Bench studies by Chang et al[3] derived a theoretical model predicting that mucus clearance velocity for oscillatory flow devices is dependent on 5 variables. These include the average air velocity and 4 other dimensionless factors: (1) the ratio of the viscosity of air to the viscosity of mucus, (2) a function of the fraction of the cross-sectional area blocked by mucus, (3) an "oscillation parameter" similar to the Wormersley number in a circular pipe (relating pulsatile flow frequency to viscous effects), and (4) a complex function of the oscillatory flow bias ratio, that is, peak inspiratory flow divided by peak expiratory flow. To summarize and compare the oscillatory flow performance of the OPEP devices, we created an oscillation index based on a simplified set of oscillatory flow characteristics described by Poncin et al[9]: oxygenation index $= f_{osc} \times \Delta\dot{V}$, where oscillation index is measured in Hz × L/min, f_{osc} is the frequency of the oscillatory flow waveform in Hz, and $\Delta\dot{V}$ is the flow waveform amplitude in L/min. Because all the observed oscillatory flow waveforms could be approximated by sinusoidal flow waveforms superimposed on the mean expiratory flows (ie, by Fourier analysis), $\Delta\dot{V}$ can be thought of as representing small flow increases, or "mini coughs" (ie, flow was always in the expiratory direction, but its value changed sinusoidally). As such, $\Delta\dot{V}$ yields approximately the same information as the flow bias ratio defined by Chang et al,[3] who reasoned that the greater the peak flows during oscillation, the greater the shear forces at the air–mucus interface. We presume that frequency and flow amplitude are key variables that may enhance mucus clearance by moving it toward the mouth or by altering mucus rheology.[2,14] Thus the oscillation index is a metric that may be used to compare the key oscillatory flow parameters of interest for OPEP devices.

Note that, in addition to altering mucus rheology, if the frequency of pressure pulsations in the lower airways is at the resonant frequency of the airways, then the flow impedance is minimized and endobronchial oscillations are maximized, perhaps maximizing mucus transport.[15] However, we reasoned that, for airways to oscillate, there had to be volumetric displacement. To achieve volumetric displacement, there has to be flow. Therefore, the frequency associated with the oscillatory flow waveform should be the one included in the calculation of oscillation index, and not the frequency of the pressure oscillation.

Results

Flow and Threshold Resistors

The results of this study generally show a large difference in performance among different brands of devices, especially the OPEP devices. Within-brand repeatability was good (reflecting good quality control), with a coefficient of variation generally ranging from 0% to 19% (2 repeated measurements yielded outliers of 34% and 45%, which were not eliminated from final data analysis).

Data for PEP devices using either flow or threshold resistance are shown in Figure 3. Increasing expiratory flow caused a continuous increase in PEP for the Resistex as expected. The Resistex graph had a different vertical axis compared to the other devices due its higher range of PEP values. The AccuPAP and AccuPEP showed virtual independence of expiratory flow and PEP. The Threshold PEP showed an increase in mean PEP from 10 to 15 L/min, and then flow independence for flows between 15 and 30 L/min. For all devices, the mean PEP was higher at each flow when the device was at the high setting.

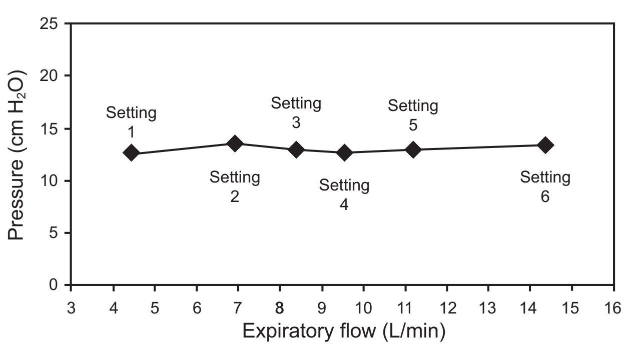

Fig. 4. Data for TheraPEP device.

Figure 4 shows data for the TheraPEP device. At each device setting, a different expiratory flow is required to reach the reference pressure indicated by the markers. Before the study, it was unclear what numeric value of PEP was achieved between the 2 reference markers. At simulated flows of 4, 7, 8, 10, 11, and 14 L/min for settings 1–6, respectively, the mean PEP at which the visual feedback marker was in in the optimal range was ∼13 cm H_2O across all settings and flows.

Data for PEP devices with external flow settings only are shown in Figure 5. Each colored line represents an external flow setting across the 6 simulated expiratory flows. For both devices, PEP is dependent on expiratory flow. The external flow setting acts like a PEP setting on threshold devices, with higher external flow generating higher PEP at each expiratory flow.

Oscillatory PEP Devices

Data for OPEP devices are shown in Figures 6–15. Each figure shows representative pressure and flow waveforms measured at a simulated expiratory flow of 15 L/min, which is the middle of the experimental flow range. There was a large difference between the shape of the pressure and flow waveforms for each device. Our results indicate that the

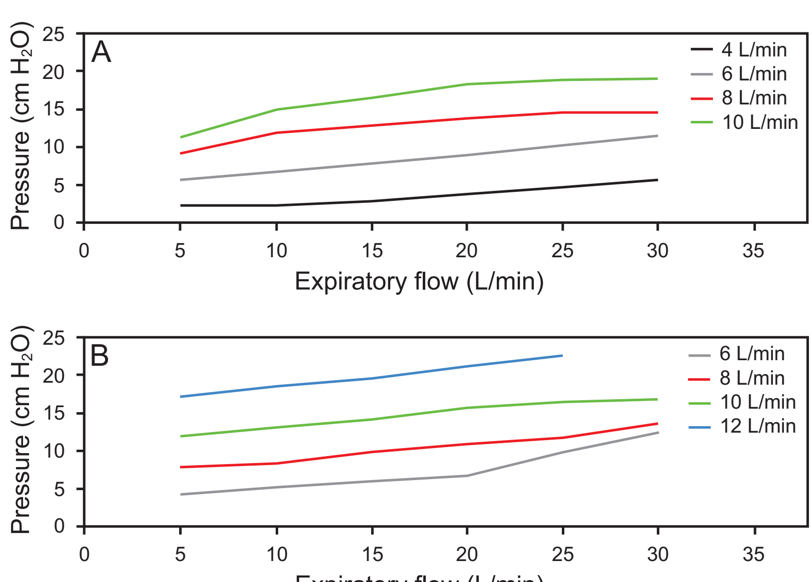

Fig. 5. Data for PEP devices requiring an external flow source. Curves represent different external flow settings. A = Ez PAP, B = VersaPAP.

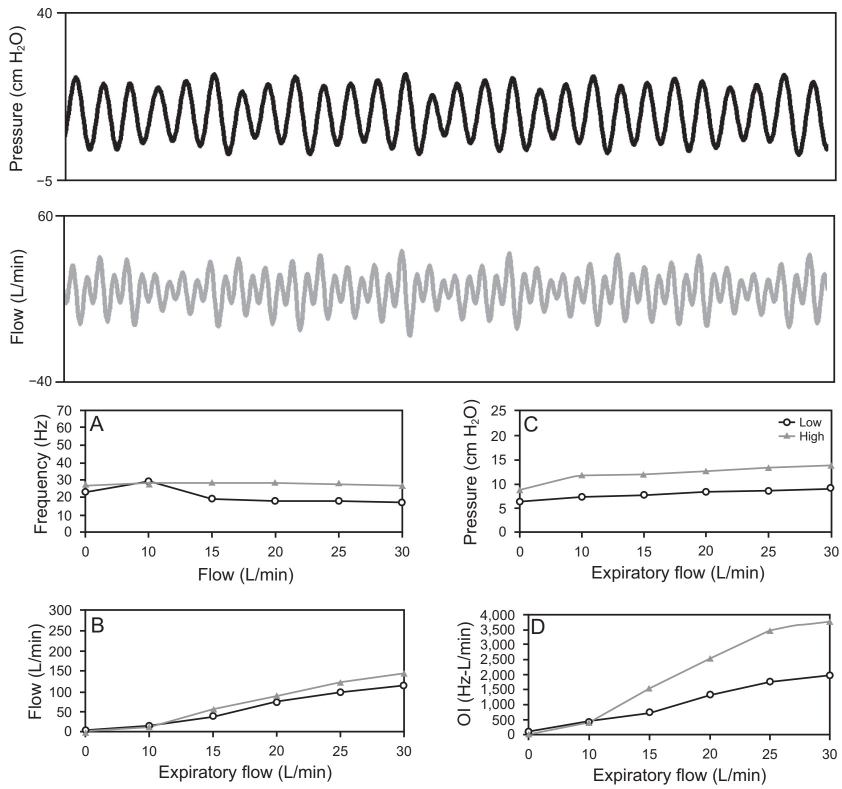

Fig. 6. Oscillatory positive expiratory pressure data for ShurClear. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

frequency of flow oscillations did not match the frequency of pressure oscillations, the latter often being much lower in amplitude. For example, while vPEP shows adequate pressure oscillation, there is virtually no flow frequency or amplitude through the device (Fig. 12). The Acapella Choice shows a similar trend of high-pressure oscillation but limited flow. Conversely, the Acapella DH and the ShurClear show waveforms with both high pressure and flow characteristics. Each figure also includes graphs of the oscillation index, flow oscillation frequency, flow oscillation amplitude, and mean PEP data for both the high and low device settings across all 6 simulated expiratory flows.

Mean PEP

Mean PEP ranged from a high of ~20 cm H_2O (Acapella Choice, Aerobika, and VibraPEP) to 0 cm H_2O (PocketPEP). For some devices, PEP was strongly flow dependent (eg, VibraPEP), while for others it was not (eg, ShurClear, vPEP, and PocketPEP). The high setting gave a higher mean PEP compared to the low setting for all devices expect the PocketPEP and PocketPEP with Oxyjet. The vPEP and vPEP with Oxyjet had almost identical mean PEP values between the high and low settings.

Flow Oscillation Frequency

Flow oscillation frequency was generally in the range of 10–30 Hz and showed little change across the 6 simulated expiratory flow settings for any device. For the vPEP and vPEP with Oxyjet, there was a substantial shift downward in flow frequency after 15 L/min flow.

Flow Oscillation Amplitude

There was wide variation in flow oscillation amplitudes among the devices, ranging from ~250 L/min (Acapella DH) to virtually 0 L/min (vPEP and PocketPEP). Flow amplitude increased with expiratory flow. For the high setting, the Acapella DH, the Aerobika, and the ShurClear had the highest flow amplitudes, respectively. However, the Acapella DH and the Aerobika had virtually no flow amplitude at the low setting. The VibraPEP showed increased amplitude frequency at 15 L/min and higher. The vPEP, vPEP with the Oxyjet, and the Acapella Choice showed very little oscillation amplitude across all expiratory flow settings. In general, all devices (except the PocketPEP) had audible pressure oscillations. Interestingly, although the vPEP had almost no flow oscillation, it did show pressure oscillation, which was audible.

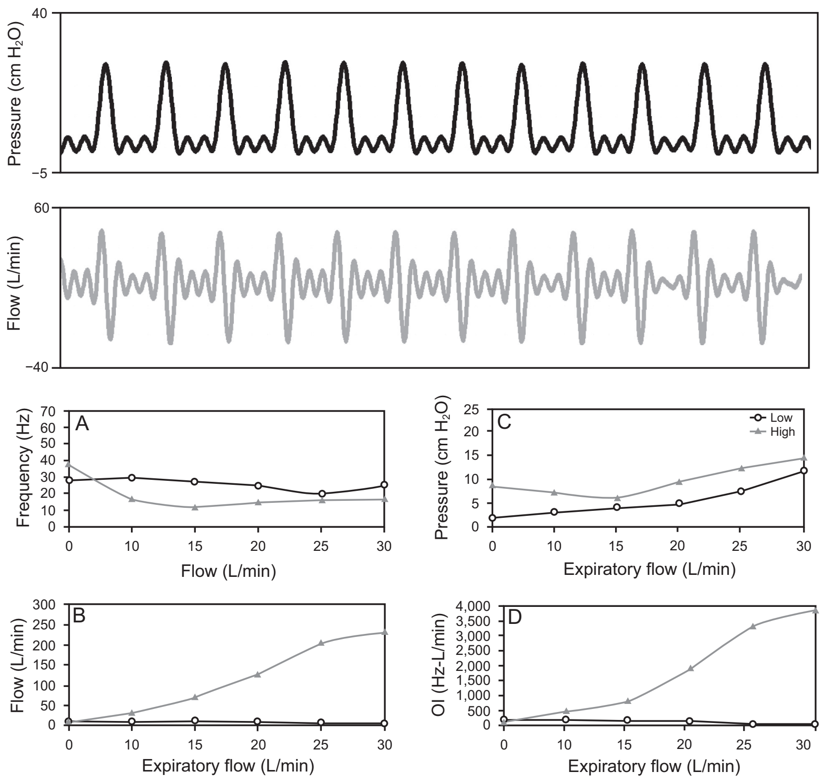

Fig. 7. Oscillatory positive expiratory pressure data for Acapella DH. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

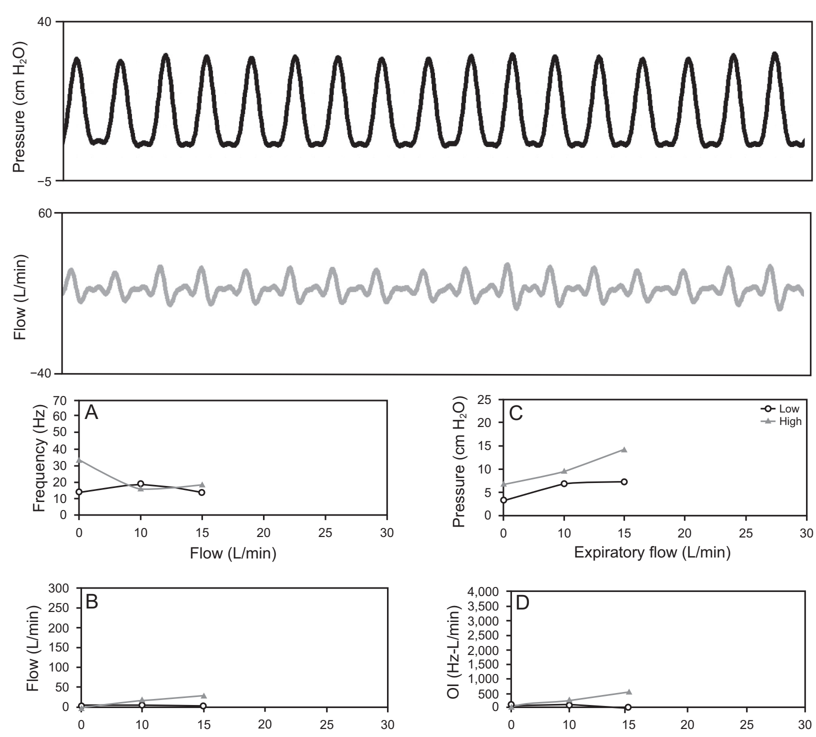

Fig. 8. Oscillatory positive expiratory pressure data for Acapella DM (pediatric model). OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

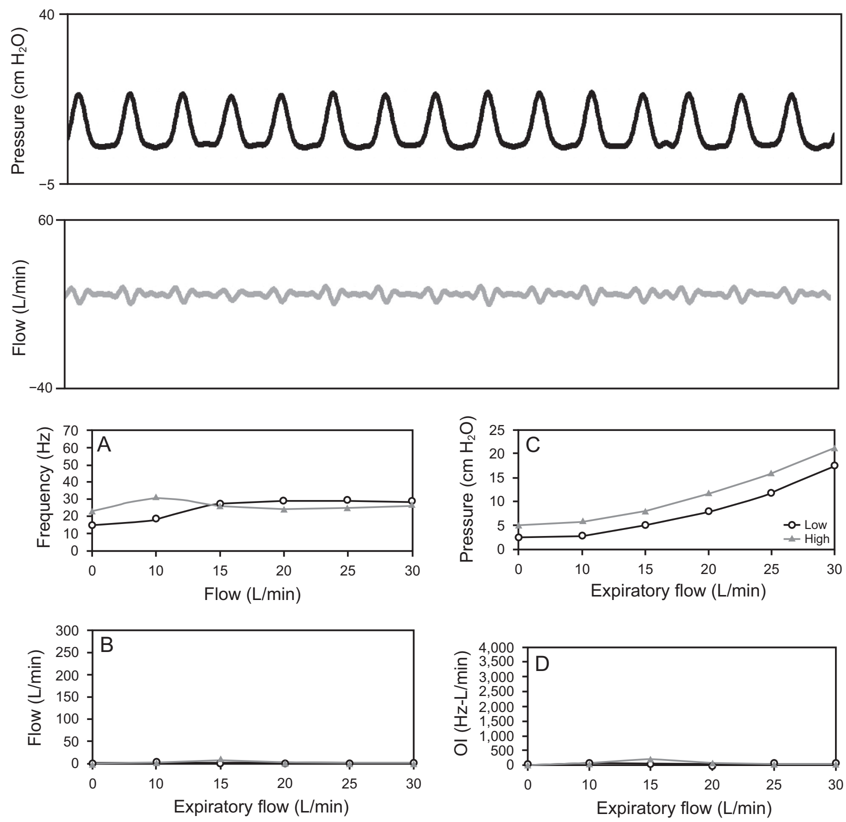

Fig. 9. Oscillatory positive expiratory pressure data for Acapella Choice. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

Oscillation Index

There was a very wide range of values for oscillation index, from a high of almost 4,000 (ShurClear) to a low of 0 (PocketPEP). At the high setting, the highest oscillation index was observed for the Acapella DH, the ShurClear, and the Aerobika. At the low setting, the highest oscillation index was for the ShurClear. The VibraPEP had the next highest oscillation index at both the high and the low setting. For all other devices except the Acapella Choice, the oscillation index increased only slightly as simulated expiratory flow increased and had a small peak oscillation index at 15 L/min. Devices that had a higher oscillation frequency and adequate mean PEP but low oscillation flow amplitude had a lower oscillation index. The PocketPEP and PocketPEP with Oxyjet both had the lowest oscillation index.

Discussion

This is the first study to include such a large variety of devices commonly used in the field of respiratory care. Our results confirm other reports that there is variability in the performance of devices designed to do the same thing.[5-7,16] For both PEP and OPEP, all devices vary in performance characteristics for each setting at a given simulated expiratory flow. Some devices had a higher flow amplitude at one setting but a better mean PEP at another; therefore, human studies are needed to determine which devices are most effective in clearing secretions.

For PEP devices that were flow resistors, we observed that increased simulated expiratory flow increased mean PEP for nearly all devices. This is to be expected and has been seen in previous studies. We observed flow independence for threshold resistors (ie, a large variation in simulated expiratory flows generated the same desired mean PEP). This characteristic may allow a single device to serve many patients at different stages of lung disease.

Other studies of OPEP have included pressure frequency and amplitude as performance characteristics, but very few studies focused on flow frequency and amplitude [5-8,13] Our study used flow frequency and amplitude as performance characteristics because previous research suggests that flow, not pressure, is the key factor for mucus clearance. The results of our study indicate that there is a substantial difference between pressure frequency and amplitude compared to flow frequency and amplitude. Chang et al[3] proposed that inspiratory and expiratory air flows enhance tracheal mucus clearance because mucus is a viscoelastic fluid. Kim et al[17] reported that an additional increase in air flow velocity on top of wave forms

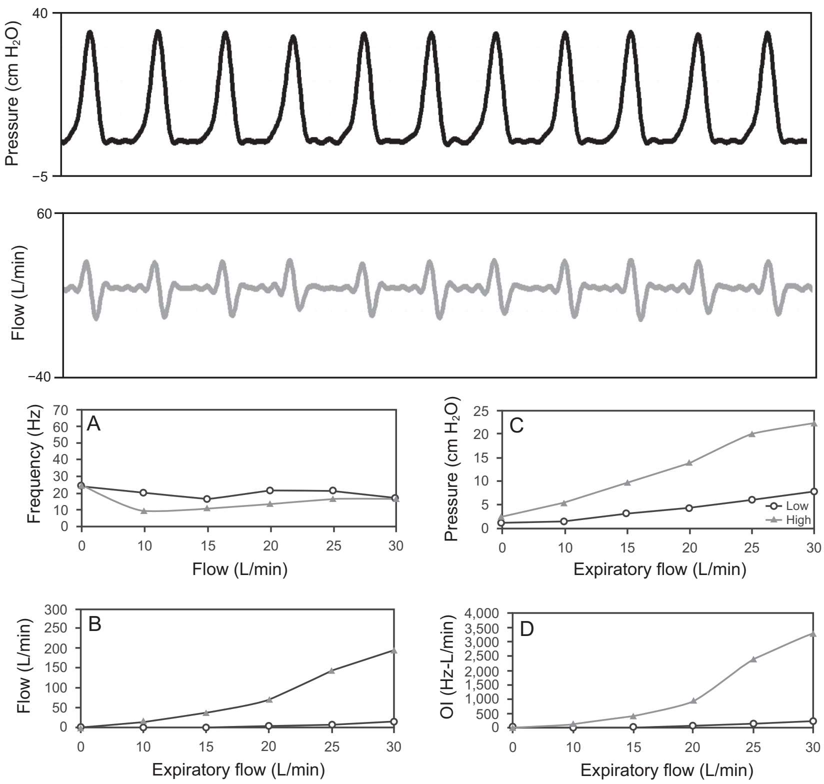

Fig. 10. Oscillatory positive expiratory pressure data for Aerobika. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

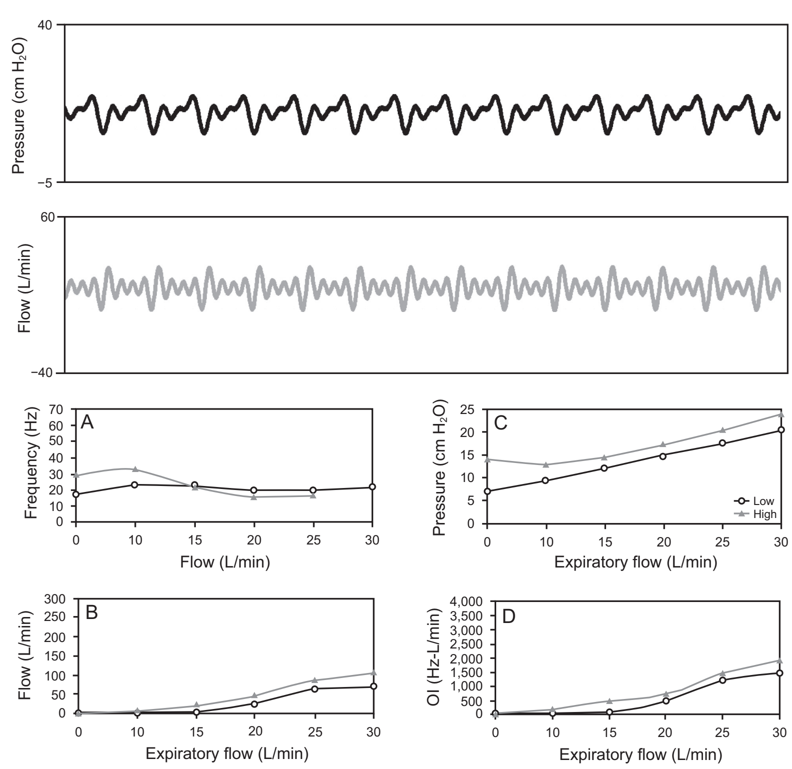

Fig. 11. Oscillatory positive expiratory pressure data for VibraPEP. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

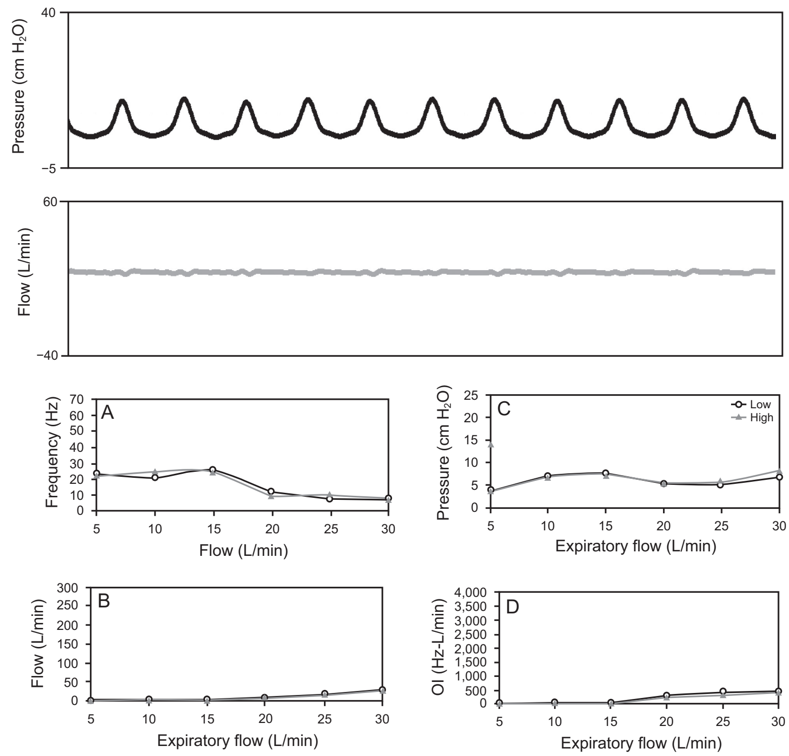

Fig. 12. Oscillatory positive expiratory pressure data for vPEP. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

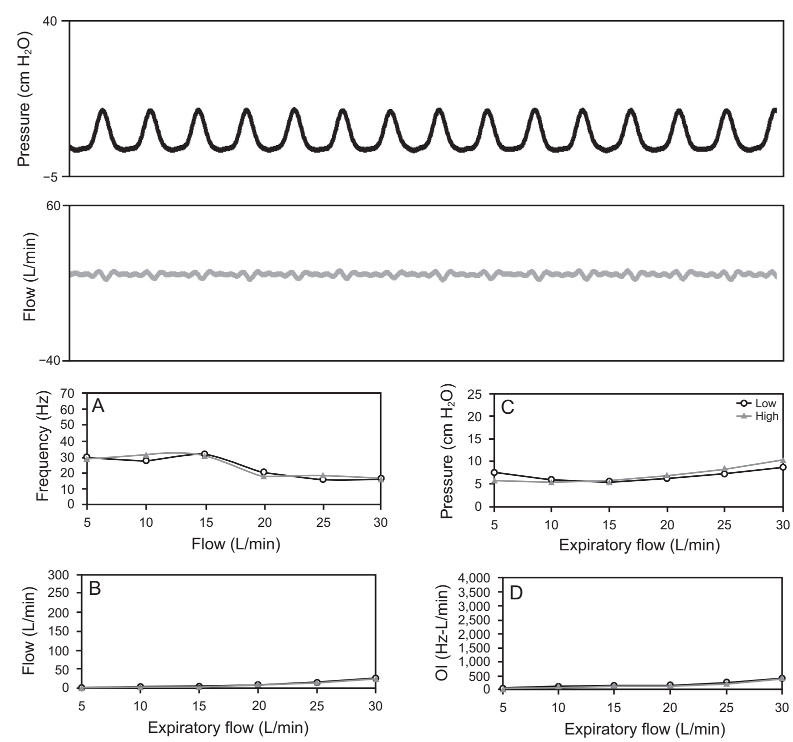

Fig. 13. Oscillatory positive expiratory pressure data for vPEP with Oxyjet. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

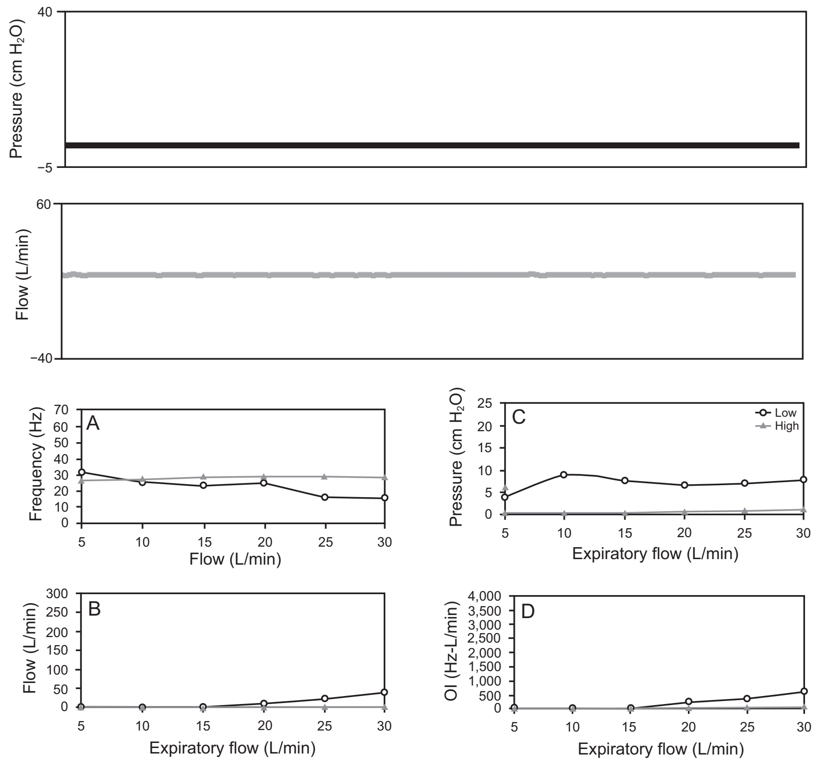

Fig. 14. Oscillatory positive expiratory pressure data for PocketPEP. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

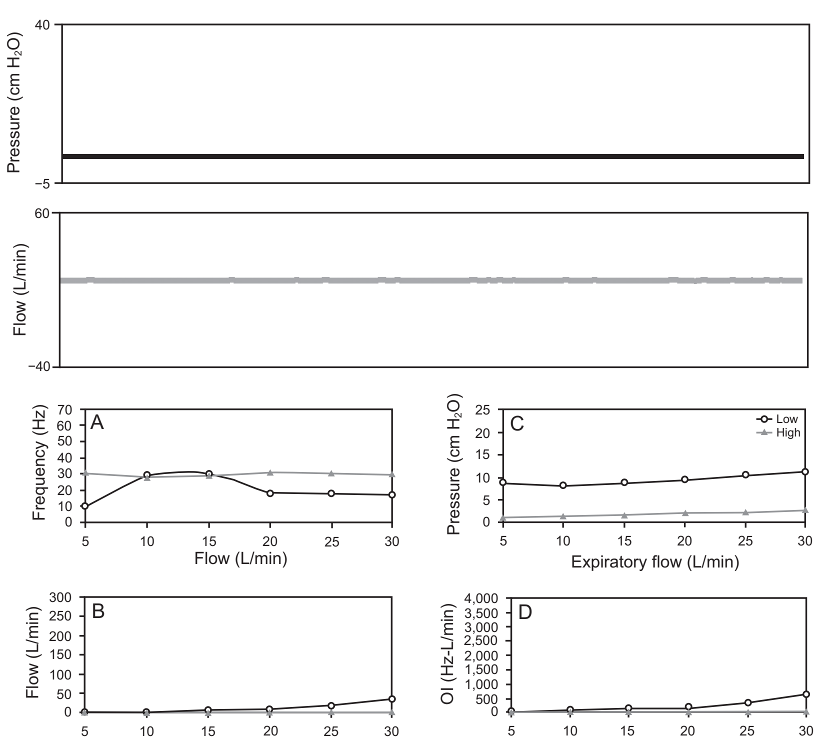

Fig. 15. Oscillatory positive expiratory pressure data for PocketPEP with Oxyjet set at 5 L/min. OI = oscillatory index. A = flow oscillation frequency, B = flow oscillation amplitude, C = mean PEP, D = oscillation index.

imposed by flow would accelerate mucus movement. Further studies have proposed that increasing the flow oscillation, causing "mini-coughs" as described in our study, may increase the effects on mucus rheology by reducing viscoelasticity.[2,13]

A study like ours, with such a large sample of devices, generates a copious amount of raw data. We created the oscillation index to quickly compare the performance characteristics of each OPEP device in an easy-to-read graph. A higher oscillation index indicates better mechanical performance characteristics. We suspect that a higher oscillation index would correlate to a better mucus clearance, although human studies would be needed to confirm this. The oscillation index emphasizes the importance of flow frequency and amplitude. Devices that have similar mean PEP but little to no flow amplitude have a much lower oscillation index compared to devices with both a high mean PEP and high flow characteristics. The data indicate that many devices have both similar mean PEP and flow oscillation frequency; however, the devices with the highest oscillation index also have the highest flow amplitude. It is a common misconception in practice that a device performs well because it produces a loud noise (ie, a pressure waveform with a large amplitude).

A major limitation of this study is that it was designed to measure the mechanical characteristics of the devices in vitro and provides no direct data on the physiologic effects of either PEP or OPEP. A digital filter had to be used to account for mechanical limitation and thus limited the accuracy of peak values for pressure and flow. However, the filter was applied to all devices, so mechanical characteristics can still be compared fairly. While this was not a human study, it does provide a wide base of knowledge about the mechanical functionality of PEP and OPEP devices that could not be achieved using human subjects. A limitation of our oscillation index is that it was designed to compare the mechanical capabilities of similar devices and needs to be validated in vivo before it can be used to describe the comparability of the devices for therapeutic use. We believe that, if a device delivers pressure oscillation but not flow oscillation, it seems doubtful that it would enhance mucus clearance.

Conclusions

PEP devices behaved similarly and as expected with increased pressure with increased flow (flow resistors) or flow independence (threshold resistors). There was much greater performance variation with OPEP devices. A higher oscillation index indicates better mechanical performance characteristics. Many devices have similar characteristics, but the devices with the highest oscillation index have the highest flow amplitude and frequency, which may indicate better clinical performance.

REFERENCES

1. Nicolini A, Mascardi V, Grecchi B, Ferrari-Bravo M, Banfi P, Barlascini C. Comparison of effectiveness of temporary positive expiratory pressure versus oscillatory positive expiratory pressure in severe COPD patients. Clin Respir J 2018;12(3):1274-1282.
2. App EM, Kieselmann R, Reinhardt D, Lindemann H, Dasgupta B, King M, et al. Sputum rheology changes in cystic fibrosis lung disease following two different types of physiotherapy: flutter vs autogenic drainage. Chest 1998;114(1):171-177.
3. Chang HK, Weber ME, King M. Mucus transport by high-frequency nonsymmetrical oscillatory airflow. J Appl Physiol 1988;65(3):1203-1209.
4. Volsko TA. Airway clearance therapy: finding the evidence. Respir Care 2013;58(10):1669-1678.
5. Franks LJ, Walsh JR, Hall K, Jacuinde G, Yerkovich S, Morris NR. Comparing the performance characteristics of different positive expiratory pressure devices. Respir Care 2019;64(4):434-444.
6. Volsko TA, DiFiore J, Chatburn RL. Performance comparison of two oscillating positive expiratory pressure devices: Acapella versus Flutter. Respir Care 2003;48(2):124-130.
7. Mueller G, Bersch-Porada I, Koch-Borner S, Raab AM, Jonker M, Baumberger M, et al. Laboratory evaluation of four different devices for secretion mobilization: Acapella choice, green and blue versus water bottle. Respir Care 2014;59(5):673-677.
8. Alves Silva CE, Santos JG, Jansen JM, de Melo PL. Laboratory evaluation of the Acapella device: pressure characteristics under different conditions, and a software tool to optimize its practical use. Respir Care 2009;54(11):1480-1487.
9. Poncin W, Reychler G, Liistro M, Liistro G. Comparison of 6 oscillatory positive expiratory pressure devices during active expiratory flow. Respir Care 2020;65(4):492-499.
10. Fagevik Olsén M, Lannefors L, Westerdahl E. Positive expiratory pressure: common clinical applications and physiological effects. Respir Med 2015;109(3):297-307.
11. George RJ, Johnson MA, Pavia D, Agnew JE, Clarke SW, Geddes DM. Increase in mucociliary clearance in normal man induced by oral high frequency oscillation. Thorax 1985;40(6):433-437.
12. dos Santos AP, Guimarães RC, de Carvalho EM, Gastaldi AC. Mechanical behaviors of Flutter VRP1, Shaker, and Acapella devices. Respir Care 2013;58(2):298-304.
13. Alves LA, Pitta F, Brunetto AF. Performance analysis of the Flutter VRP1 under different flows and angles. Respir Care 2008;53(3):316-323.
14. Pieterse A, Hanekom SD. Criteria for enhancing mucus transport: a systematic scoping review. Multidiscip Resp Med 2018;13(22)
15. Morrison L, Innes S. Oscillating devices for airway clearance in people with cystic fibrosis. Cochrane Database Syst Rev 2017;5:CD006842.
16. Morgan SE, Mosakowski S, Giles BL, Naureckas E, Tung A. Variability in expiratory flow requirements among oscillatory positive expiratory pressure. Can J Respir Ther 2019;56:7-10.
17. Kim CS, Rodriguez CR, Eldridge MA, Sackner MA. Criteria for mucus transport in the airways by two-phase gas-liquid flow mechanism. J Appl Physiol 1986;60(3):901-907.