Technical Aspects of Devices and Equipment for Positive Expiratory Pressure With and Without Oscillation

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BACKGROUND: Breathing exercises with positive expiratory pressure (PEP) and oscillating PEP are common treatments for patients with respiratory impairments. There are several trials evaluating the clinical effects of a variety of commercially available and self-made devices. There is a lack of evaluation concerning technical aspects and construction of the devices. The aims of this review were to describe and compare technical aspects of devices and equipment used for PEP and oscillating PEP as a basis for clinical decisions regarding prescriptions. METHODS: In this systematic review, we included trials evaluating different technical aspects of devices and equipment for PEP and oscillating PEP until June 2019. The literature search was performed in PubMed, CINAHL, Cochrane Library, Embase and PEDro. RESULTS: The literature search resulted in 812 studies, which, after being read by 2 independent reviewers, were reduced to 21 trials that matched the inclusion criteria. The achieved PEP is dependent on the given resistance or achieved expiratory flow through the devices and their separate parts. Oscillation frequency in oscillating PEP devices affects the pressure and oscillation amplitude and flow. For some devices, the device's position also has an impact on the outcome. There are similarities and differences among all of the devices, and the equipment components are not interchangeable without changing the achieved PEP levels. CONCLUSIONS: Many devices are available to provide PEP and oscillating PEP treatment. These devices differ substantially in design as well as in performance. When using PEP devices, it is important to understand how all parts of the devices affect outcomes. An increased understanding of how PEP is produced for the spontaneously breathing patient is important to achieve desired treatment effects. *Key words: breathing exercises; oscillatory; positive expiratory pressure; pressure.* [Respir Care 2021;66(5):862–877. © 2021 Daedalus Enterprises]

Introduction

Breathing exercises with positive expiratory pressure (PEP) and oscillating PEP is used by different categories of patients all over the world. PEP and oscillating PEP devices refer to medical devices and equipment designed to create resistance upon expiration during spontaneous breathing. The first commercial device, the PEP/RMT-set, was developed in Denmark in the late 1970s.[1] It was initially used to increase lung volume to facilitate mucus clearance in patients with pulmonary disease, but it was also used for respiratory muscle training.[1] However, expiration against resistance has been used spontaneously for centuries by patients with obstructive pulmonary disease in the form of pursed-lip breathing, which is a physiological response to decrease hyperinflation and thereby reduce dyspnea and the work of breathing with air flow limitation.[2]

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The positive pressure during expiration is created by an applied resistance that restricts the expiratory flow or may voluntarily be performed by expiring through pursed lips. A simple technique to create the resistance is to use a tube or straw with a small orifice to reduce the expiratory flow. Today, however, there are many devices on the market that are either flow-regulated or pressure-regulated or have an oscillating resistance. Flow-regulated devices have different constructions with holes that create the resistance to expiration. Pressure-regulated systems have thresholds where a predetermined pressure must be achieved before expiration can start. In addition, the flow and pressure can be oscillating produced by exhaling into a bottle of water or by using specially designed devices. These products provide high-frequency oscillation during expiration by changing the resistance and subsequently the pressure. The oscillation frequency and flow amplitude depend on the resistance and the expiratory force.

The equipment and devices are used to increase expiratory pressures for totally different physiological reasons.[3] For example, postoperatively, sessions of breaths with PEP temporarily increase lung volumes to reduce atelectasis and risk of pulmonary complications. Conversely, each expiration with a reduced flow due to the expiratory resistance will keep airways open to decrease hyperinflation and work of breathing in patients with chronic obstructive diseases.[3] The aim of the oscillation in oscillating PEP is to augment the natural resonance in the airways and thereby facilitate the loosening of mucus and reinforce the effects of mucociliary clearance.[3]

There are several dissimilarities between available PEP devices, so the devices are not interchangeable or directly comparable, which is important. In addition, not all devices, brand names, and techniques are available everywhere in the world. Knowledge about the similarities and differences between systems and devices is therefore necessary to provide high-quality care with whatever devices are available.

We identified several reviews and meta-analyses evaluating the effect of PEP and oscillating PEP to prevent or treat breathing disorders or dysfunction.[4-6] The studies included in these reviews are often small, so the outcome measures sometimes are not be sensitive or valid; sometimes the evaluated interventions are not fully described, and the desired results may not be achieved as a nonoptimal dose or intensity is evaluated. In addition, there is often a heterogeneity in the study populations, and the equipment or devices used are seldom described and discussed. The choice of PEP equipment and how patients are instructed to use it have an impact on the treatment effects. To our knowledge, a comprehensive summary of studies evaluating technical aspects of PEP devices has not been presented.

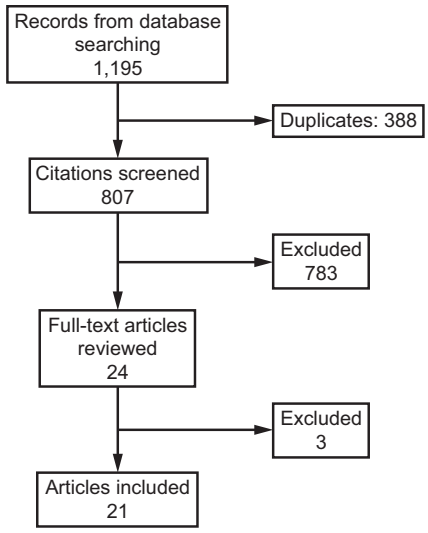

Fig. 1. Flow chart.

The aims of this review were therefore to describe and compare technical aspects of devices and equipment used for PEP and oscillating PEP as a basis for clinical decisions before prescribing.

Methods

This systematic review includes studies evaluating technical aspects of devices and equipment used for PEP and oscillating PEP treatment. We searched for studies published up to July 2019 that evaluated the performance of PEP devices or equipment, as bench studies or in a clinical setting. Inclusion criteria were as follows: study purpose had to assess technical aspects and construction or design of devices for PEP and oscillating PEP (ie, comparisons of configuration of resistance and pressure stability); study design was a randomized controlled trial, a controlled trial, or an observational experimental study. We excluded narrative review articles, meeting abstracts, clinical studies evaluating exclusively the treatment effects of PEP and oscillating PEP or subjects' experiences with the treatment, studies that evaluated pursed-lips breathing, studies evaluating PEP and oscillating PEP devices attached to nebulizers/aerosols, and studies in languages other than English.

Literature Search

A systematic search of the literature in the PubMed, CINAHL, Cochrane Library, and Embase databases was conducted on June 3, 2019, by a librarian at Örebro University. The search strategy is presented in Figure 1. The key words were formulated in PubMed and adapted

Table 1. Details of the 21 Included Articles

Study	Year	Journal	Country	Provider (Profession)
Alves et al[7]	2008	RESPIRATORY CARE	Brazil	Physical therapist
Alves Silva et al[8]	2009	RESPIRATORY CARE	Brazil	Physical therapist
Boden et al[9]	2017	Pulmonology & Respiratory Research	Australia	Physical therapist
Brooks et al[10]	2002	Journal of Cardiopulmonary Rehabilitation	Canada	Physical therapist
Christensen et al[11]	1995	Monaldi Archives for Chest Disease	Denmark	Physician
Clase Larsson et al[12]	2006	Advances in Physiotherapy	Sweden	Physical therapist
Dagan et al[13]	2014	Physiotherapy Canada	Israel	Physical therapist
de Lima et al[14]	2005	Medical Engineering & Physics	Brazil	Engineer
dos Santos et al[15]	2013	RESPIRATORY CARE	Brazil	Physical therapist
Fagevik Olsén et al[16]	2015	RESPIRATORY CARE	Sweden	Physical therapist
Franks et al[17]	2019	RESPIRATORY CARE	Australia	Physical therapist
Matsuo et al[18]	2014	Cardiopulmonary Physical Therapy	Japan	Physical therapist
Mestriner et al[19]	2009	RESPIRATORY CARE	Brazil	Physical therapist
Mueller et al[20]	2014	RESPIRATORY CARE	Switzerland	Movement scientist
Phimphasak et al[21]	2018	RESPIRATORY CARE	Thailand	Physical therapist
Pursley[22]	2017	Respiratory Therapy	USA	Respiratory therapist
Santos et al[23]	2017	RESPIRATORY CARE	Australia	Physical therapist
Santos et al[24]	2020	Physiotherapy Theory & Practice	Australia	Physical therapist
Sehlin et al[25]	2007	RESPIRATORY CARE	Sweden	Physical therapist
Van Fleet et al[26]	2017	RESPIRATORY CARE	USA	Respiratory therapist
Volsko et al[27]	2003	RESPIRATORY CARE	USA	Respiratory therapist

to the other databases. The search was based on the following search string: "positive expiratory pressure" OR "positive-pressure respiration" OR "intermittent positive-pressure ventilation" OR "resistance breathing" OR "resistive breathing" AND ("physical therapy modalities" OR "physical therapy" OR "physiotherapy" OR "breathing exercises"). Duplicates were eliminated by the librarian in charge of the search.

The PROSPERO database was searched on October 14, 2019, for ongoing systematic reviews using the keyword "positive expiratory pressure"; 19 study protocols were found, but none were relevant to our research question. At ClinicalTrials.gov, the international database for clinical trials, 14 study protocols for randomized controlled trials were found related to positive expiratory pressure and physiotherapy, but none were relevant.

Data Extraction

Two independent researchers (MFO, EW) reviewed the search results by reading titles and abstracts. Articles were selected when either of the 2 judges deemed it appropriate; these articles were read in full and ultimately were included if they were still considered to meet the inclusion criteria. Reference lists were checked for relevant studies. No assessment of methodological quality of the included studies was performed.

Results

The characteristics of the included trials are presented in Table 1. In total, 21 articles published from 1995 to 2018 were found; 11 of them were published since 2010. The research was undertaken in Brazil (5 articles), Australia (4), Sweden (3), the United States (3), Denmark, Canada, Israel, Japan, Switzerland, and Thailand (1, respectively). The majority (12 of 21) were published in the scientific journal RESPIRATORY CARE, and another 5 were published in physiotherapy journals (Table 1). There are several professions represented among the first authors (Table 1).

Information about the aims of the included articles and a summary of their methods and results are presented in Table 2. The results of the trials are presented below and divided under subheadings regarding different device designs. Detailed information about the devices' brand names and manufacturers are presented in Table 3. If the named manufacturer differed between articles, the latest published manufacturer was included in the table.

Flow-Regulated PEP-Devices

Flow-regulated PEP devices contain a 1-way valve, and the expiration goes through a narrow opening with a specific diameter. The level of expiratory pressure achieved in the system is determined by the expiratory flow, the diameter of the opening, and the design of the hole used. A manometer can be used to measure the pressure achieved in the system.

Table 2. Aim, Methods, and Results of the Included Trials

Study	Device or Equipment	Aim	Methods	Results
Alves et al[7]	Flutter VRP1	To quantify effects of pressure, oscillation, and amplitude at different angles and flows and to determine at which flow and angle the device's airway clearance had an optimal effect.	Mean pressure, oscillation frequency, and flow amplitude were determined at angles of –30° to +30° and flows of 12–120 L/min. Define the "ideal" angle for a mean pressure of 10–20 cm H_2O and oscillation frequency of 12 Hz.	Higher mean pressure at 30° at higher flows and 15° at all flows; lower values at –30° at lower flows and 0° at intermediate flows ($P < .01$). Higher oscillation frequencies at 30° and 15° and lower at –30° and –15°at all flows ($P < .01$). Higher flow-amplitude values at 30°, 15°, and 0°, and lower values at –30° and –15° ($P < .01$). Mean pressure of 10 cm H_2O was reached with the lowest flow (12 L/min) at 30°, and mean pressure of 20 cm H_2O was produced at 15° (60 L/min), whereas an oscillation frequency of 12 Hz was reached at 0°, –30°, and –15° at 12 L/min
Alves Silva et al[8]	Acapella	To characterize the mechanical behavior (ie, mean pressure, oscillation frequency, and amplitude) and to develop a software tool to ease the practical use of the device.	Mean pressure, oscillation frequency, and oscillation amplitudes in 3 Acapella (model green) in the whole range of instrument adjustments and under 12–18 L/min.	Oscillation frequency was 8–21 Hz, mean pressure was 3–23 cm H_2O, and oscillation amplitude was 4–9 cm H_2O; all increased with flow and instrument adjustment.A user-friendly software was developed, incorporating the current knowledge concerning secretion removal.
Boden et al[9]	Tube PEP	To compare pressures generated by different lengths of 4-mm tubes and to estimate if therapeutic PEP could be delivered.	Pressure in tubes with 4 mm internal diameter and lengths of 40, 60, 80, 100, and 120 cm was tested at flows of 4–11 L/min.	A strong positive linear relationship between pressure and flow across lengths of tubing up to 120 cm with flows of 4–11 L/min was seen. Regression modelling can estimate pressures generated at 20 L/min.
Brooks et al[10]	Flutter	To determine the effect of flow and the device angle at the mouth on expiratory pressure and oscillation frequency.	Flow, expiratory pressure, and oscillation frequency were measured with the device in angels from +40° to –40°.	There was a strong and significant correlation between flow and expiratory pressure at each level of incline. There was also a significant and strong correlation between expiratory pressure and oscillation frequency. There was a significant reduction in expiratory pressure at a negative incline of 40°.
Christensen et al[11]	Pari-PEP, PEP/RMT-set, System 22-PEP, underwater seal, Vital Sign and AMBU PEEP valve	To evaluate the flow-regulated properties of flow-dependent PEP, an underwater seal, and 2 threshold resistor devices.	Pressure at constant flow of 3–150 L/min was measured with the 3 flow-regulated PEP systems with resistor diameters of 1.5-5.0 mm, and the 3 threshold devices with PEEP values of 0–20 cm H_2O.	The flow-regulated PEP systems gave an increased pressure with flow dependent on the orifice of the resistor. The underwater seal and PEEP from Vital Sign were stable in pressure in contrast to the AMBU PEEP, which showed higher pressure at higher flows. Both threshold devices gave higher pressures compared with indicated pressure.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Clase Larsson et al[12]	PEP/RMT via mask or mouthpiece	To investigate PEP using mask or mouthpiece regarding pressure, dead space volume, performance, and perceived exertion in postoperative care.	Pressure in a PEP valve, connected to a mask or mouthpiece in 20 volunteers, was measured under constant flows and resistances.Dead space in each system was measured with water. Degree of leakage from the device was observed in 40 patients undergoing abdominal surgery.	Higher pressure with mouthpiece than with mask, irrespective of flow and resistance ($P < .05$). Dead space greater with mask (170 vs 26 mL). In the clinical part, there were no significant differences between the groups in degree of leakage.
Dagan et al[13]	Blow-glove device and Resistex PEP	To document expiratory pressure in gloves of different sizes and composition with different volumes and flows and to compare with Resistex.To determine the effect of repeated inflations.	PEP with volumes of 0.4–2 L and expiratory flows at 10–80 L/min were compared between a Resistex and a blow-glove device connected to a ventilator.The blow-glove device was evaluated using various glove compositions and sizes.	The blow-glove device produced a significantly higher pressure in the recommended range than Resistex (88.9% vs 20%, $P < .0001$). No significant difference was observed between small and large glove sizes (88.9% vs 82.9%, $P > .05$), but the powdered latex glove showed a significantly higher rate of PEP values in the recommended range than the powder-free latex glove (88.9% vs 44.4%, $P < .001$).
de Lima et al[14]	Flutter VRP1	To characterize the mechanical behavior of the Flutter VRP1.	Oscillatory frequency of the sphere at different flows (30–350 L/min), fluid pressures, angular orientations (30°, 0, and –30°), sphere materials (stainless steel, aluminum, Tecnew, and Teflon), and sphere weights (4.2–27.9 g) were studied in an experimental set-up.	The original stainless steel sphere produced high levels of pressure (> 80 cm H_2O) at flows > 180 L/min; lighter spheres reduced pressure levels by up to 40%. The pressure differed as the device angle changed.
dos Santos et al[15]	Flutter VRP1, Shaker, Acapella	To compare the mechanical performance of the Flutter VRP1, Shaker, and Acapella devices.	Pressure, flows, and oscillation frequencies were standardized, measured with flows of 5–32 L/min with Flutter VRP1 (at 30°, 0°, –30°), Shaker, and Acapella (with intermediate, higher, and lower levels of resistance).	The mechanical behavior of the Shaker device was similar to that of Acapella, but with better linearity at higher flows. The pressure amplitude produced by the Flutter and Shaker devices was greater at low and high pressures. The Acapella device produced similar pressure amplitude at intermediate pressure. The frequency of oscillation was higher for the Flutter and Shaker devices at intermediate pressure. The levels of positive expiratory pressure produced by the 3 devices were similar. All 3 devices produced pressure and oscillation, which aid in the transport of respiratory secretions.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Fagevik Olsén et al[16]	Resistors from PEP/RMT, Pipe P, and Mini-PEP (15-mm endo-adapter)	To compare pressures generated from the proprietary resistor components of 4 flow-dependent PEP valves with all other parameters kept constant.	Resistors of all sizes from 4 flow-regulated PEP devices (PEP/RMT system, Pipe P breathing exercises, Mini-PEP with resistors by Rüsch; with a 15-mm endo-adapter) were tested randomly by a blinded tester at flows of 10–18 L/min. All resistors were tested 3 times.	Resistors with a same diameter produced significantly different pressures at the same flow. The differences were smaller at a flow of 10 L/min than at 18 L/min. The differences were less when the inner diameter was increased. The pressures with the same size of the 4 resistors were significantly different when measuring 1.5- and 2.0-mm resistors at a flow of 10 L/min and when measuring 2.0-mm resistors at a flow of 18 L/min ($P <$ .001), but there were no significant differences between the 4.5- and 5.0-mm resistors at either flow. The Mini-PEP and adapter resistors gave the highest pressures.
Franks et al[17]	Flutter, Pari PEP S, Acapella Choice, Acapella DM, Acapella DH, Aerobika	To compare the performance characteristics of 6 airway clearance devices by varying resistance and flow.	Mean PEP, peak PEP, oscillation frequency, and amplitude PEP were measured for each device at flows of 5–30 L/min and at low, medium, and high resistance.	Mean pressure increased during increasing flows against fixed resistances with the Acapella Choice, Acapella DH, Aerobika, and Pari PEP S; there was minimal change with the Flutter and Acapella DM. At a fixed flow, increasing resistance increased mean pressure in all devices except the Acapella Choice. Peak pressure increased with increased flow in all devices except the Acapella DH and Acapella Choice. Increasing resistance increased peak pressure with the Acapella DM, Aerobika, and Pari PEP S; there was minimal change for the Flutter and Acapella Choice. Oscillation amplitude increased with all devices except the Acapella DH and Acapella Choice. Oscillation frequency increased during increasing flow for all devices except the Flutter; increasing resistance either maintained or increased oscillation for all devices.Amplitude pressure was either maintained or increased during oscillations for all devices except the Flutter when resistance increased.
Matsuo et al[18]	Threshold PEP	To investigate whether the expiratory pressures of the Threshold IMT used in reverse reflects the pressures calibrated for inspiratory muscle training (IMT), which would enable both IMT and EMT to be performed with the same device.	Two tests were performed to compare the Threshold IMT device-in-reverse pressure to that of the actual pressure measured under 2 separate conditions including manually generated expiratory flow using a bag-valve-mask device and expiratory flow generated by 6 healthy subjects.	The first test examining the effects of air flow introduced via bag showed that the pressure quickly achieved the calibrated pressure and then decreased slightly, though pressure remained similar to that calibrated on the threshold IMT device. The second test showed similar results, but with greater maintenance of the Threshold IMT device calibrated pressure. No significant difference was observed between the Threshold IMT device-in-reverse pressures and those that were measured directly during both tests.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Mestriner et al[19]	PEP-bottle, tube diameter and length	To investigate if tube diameter and length, and the diameter of the PEP bottle's air-escape orifice would impact PEP and to determine whether the PEP bottle acts as a threshold or a fixed-orifice resistor.	A bottle with water and a tube 10 cm below the surface was connected to a pneumotachometer and a manometer, to evaluate the effects of various tube diameters (range 2–25 mm) and lengths (range 20–80 cm) during flows of 1–25 L/min. Tests were done with an open top and closed top except for an air-escape orifice of 4, 6, 8, 9, or 10 mm.	With tubes of 2–6 mm inner diameter, the length of the tube and the flow significantly affected the pressure (ie, the system was not a threshold resistor). With tubes of > 8 mm inner diameter, there were no significant PEP differences with any of the tube lengths or flows tested, which indicates a threshold-resistor system. The 4-mm and 6-mm air-escape orifices significantly increased the PEP pressure, whereas the 8 mm air-escape orifice did not increase the PEP.
Mueller et al[20]	Acapella and PEP-bottle	To evaluate the 3 different Acapella devices and the water bottle at various settings and flows to determine the optimal device and settings for effective secretion removal.	Three different Acapella devices were tested at flows of 6–50 L/min and at all 5 settings. The water bottle was filled with 5–15 cm of water and tested at flows of 3–20 L/min. Frequency and amplitude of the vibrations were tested, and the required pressure to generate vibrations was measured.	Setting 4 was the best for all 3 Acapella devices, and the filling height of the water bottle should be 5 cm. At these settings, all devices elicited vibration frequencies at 12–15 Hz, which is theoretically optimal for secretion mobilization. The resistance pressures of the devices to elicit these vibrations were 5–11 cm H_2O. The Acapella devices produced higher vibration amplitudes (5–8 cm H_2O) than the water bottle (1.8 cm H_2O).
Phimphasak et al[21]	Conical PEP device	To determine the pressure-flow relationships in different designs of resistors to find a design that generated clinically useful levels of pressure over a range of flows that might be experienced during exercise.	Investigators made orifice resistors with holes in plastic discs 0.1 mm thick, and made cone resistors by rolling 0.1-mm plastic sheets into cones 1–4 cm in length with orifices of 5–7 mm. The pressures generated by 8 different resistors were measured 3 times at flows of 6–90 L/min.The resistors' effect on cardiopulmonary function and dyspnea during exercise in young and older men were tested.	For a given flow, pressure decreased as the cone length decreased and orifice size increased. A 1-cm cone with a 6-mm orifice generated pressures of 5.2 and 18.3 cm H_2O at flows of 30 and 54 L/min, respectively; with a 7-mm orifice, pressures were 4.9 and 19.1 cm H_2O at flows of 30 and 66 L/min, respectively. The choice of orifice size for a subject depended on his or her estimated expiratory flow; larger flows required the larger orifice to generate an expiratory pressure of 5–20 cm H_2O. Breathing with the conical PEP device did not affect exercise time, dyspnea, minute ventilation, heart rate, or blood pressure.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Pursley[22]	vPEP, Aerobika, and Acapella	To analyze maximum expiratory flow during oscillating PEP therapy by comparing flow-volume loops generated by the vPEP, Aerobika, and Acapella during simulated spontaneous breathing.	Maximum expiratory flow, frequency, mean expiratory pressure, maximum inspiratory flow, mean pressure amplitude, and mean flow amplitude were measured at volumes of 400–2,000 mL.	Maximum expiratory and inspiratory flows increased progressively with volume increases in all 3 devices. Resistance had a significant effect on expiratory flow but not on inspiratory flow. There was a significant difference in expiratory flow between all 3 devices when compared to each other and in inspiratory flows between the vPEP and Aerobika and the Acapella and Aerobika, but not between vPEP and Acapella.Peak-to-peak flow oscillatory amplitude tended to increase progressively or increase and plateau with increases in volume.There was a direct relationship between frequency and inspiratory volume. The higher the inspiratory volume, the higher the frequency. Changing the resistance from low to high had minimal impact on frequency for the vPEP and Aerobika, but the impact was more significant on the Acapella.There was a direct relationship between expiratory mean airway pressure and inspiratory volume. The higher the inspiratory volume, the higher the expiratory mean airway pressure; the most profound effect was seen on the Acapella.
Santos et al[23]	Therapist made PEP-bottle, AguaPEP, Hydrapep, and Therabubble	To determine the end-expiratory pressures and oscillation frequencies generated when a range of flows were applied to five bubble-PEP devices.	Pressures and oscillation frequencies were tested at flows of 5–25 L/min in 5 devices: a therapist-made bubble-PEP 3-cm device (13 cm of water, tube 3 cm from the base of the container); a therapist-made bubble-PEP 0-cm device (10 cm of water, tube at the base of the container); and the AguaPEP, Hydrapep, and Therabubble devices with water to the 10-cm mark on the containers.	Bubble-PEP 3-cm device: pressure of 1.4–1.8 cm H_2O, oscillations of 13–17 HzBubble-PEP 0-cm device: pressure of 1.9–12.9 cm H_2O, oscillations of 12–14 Hz;AguaPEP: pressure of 9.7–11.5 cm H_2O, oscillations of 11–17 HzHydrapep: pressure of 9.6–10.7 cm H_2O, oscillations of 14–17 HzTherabubble: pressure of 8.6–12.8 cm H_2O, oscillations of 14–17 HzBubble-PEP 3-cm device maintained the most stable pressure throughout the range of flows tested. All of the devices produced similar oscillation frequencies.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Santos et al[24]	Therapist-made PEP-bottle	To determine expiratory pressures and oscillation frequencies generated in the therapist-made bubble-PEP device using tubes with different internal diameters.	Therapist-made bubble-PEP device with 10 cm of water and tube length of 30 cm with distal end of the tubing resting 3 cm from base of container. Tubes with inner diameter of 2–10 mm were tested at flows of 5–25 L/min. A pressure transducer measured the pressures and oscillation frequencies.	At flows of 5 and 10 L/min, the 2-mm tube had pressures of 2.1 and 41.8 cm H_2O, respectively, and oscillation of 15–19 Hz.At flows of 5 and 25 L/min: 4-mm tube: pressures of 12.5 and 41.5 cm H_2O, respectively, and oscillations of 14–18 Hz5-mm tube: pressures of 1.9 and 15.8 cm H_2O, respectively, and oscillations of 17–18 Hz7-mm tube: pressures of 10.7 and 12.7 cm H_2O, respectively, and oscillations of 14–17 Hz8-mm tube: pressures of 1.5 and 11.4 cm H_2O, respectively, and oscillations of 14–18 Hz 10-mm tube: pressures of 1.4 and 1.8 cm H_2O, respectively, and oscillations of 13–17 Hz
Santos et al[24]				The tube with an inner diameter of 10 mm generated the most stable PEP in relation to water height (10 cm) regardless of flow compared to tubing with an inner diameter of 2, 4, 5, 7, or 8 mm.
Sehlin et al[25]	PEP-bottle, PEP/RMT	To measure the airway pressure and expiratory air flow with the PEP bottle and the PEP mask, and to evaluate perceived exertion during breathing in the devices.	Airway pressure and flow were tested in 20 healthy volunteers with 3 sessions of 10 breaths with the PEP bottle 10 cm of water and a 42-cm plastic tube (1 cm inner diameter) and the PEP/RMT, mask, and resistors (individually chosen resistors resulting in a PEP of 10 cm H_2O), with a rest period of 15 min between measurements.	With the PEP bottle, the expiratory phase began with a zero-flow period of 0.39 s, during which pressure rose to 11.9 cm H_2O. Mean pressure was 11.7 cm H_2O, and end-expiratory pressure was 9.5 cm H_2O. Inspiration also began with a zero-flow period of 0.43 s, during which airway pressure decreased 9.6 cm H_2O from the end-expiratory airway pressure. With the PEP/RMT, the initial expiratory zero-flow period was 0.04 s and showed no change in airway pressure. The shape of the pressure curve was different; mean pressure was 8.6 cm H_2O, and end-expiratory pressure was zero. Inspiratory zero-flow period was 0.01 s, and there was no change in airway pressure.

(Continued)

Table 2. Continued

Study	Device or Equipment	Aim	Methods	Results
Van Fleet et al[26]	Acapella, RC-Cornet, Flutter, and Aerobica	To describe differences in functional characteristics of 4 oscillating PEP devices concerning peak pressure, PEP, oscillatory frequency, and pressure amplitude.	Standardized breaths with airway resistance of 17.1 cm H_2O/L/s, pulmonary compliance of 42.1 mL/cm H_2O, active exhalation of 22 breaths/min, and tidal volume of 409 mL. Resistance settings for the Acapella, RC-Cornet, Flutter, and Aerobika were adjusted to low, medium, and high. Values for frequency, peak pressure, PEP, and pressure amplitude were recorded for 1 min.	Significant effects for time, device, and resistance were noted for peak pressure, PEP, and pressure amplitude at each resistance level, demonstrating that the devices functioned differently as > 1 repetition of a series of consecutive active exhalations were performed. Significant interaction effects for device, resistance level, and time indicate inconsistent output for peak, PEP ($P < .01$), and pressure amplitude. Oscillation frequencies were within the respective manufacturers' operational parameters. The Aerobika provided the most consistent pressure amplitude across resistance settings and produced the highest mean pressure amplitude at medium and high resistance settings.
Volsko et al[27]	Acapella, Flutter	To compare mean PEP, oscillatory pressure amplitude, and frequency in Acapella and Flutter over a clinically relevant range of flows.	Oscillatory amplitude, PEP, and frequency were measured at flows of 5–30 L/min. The devices were adjusted to give low, medium, and high mean expiratory pressure (Flutter angle at 0°, 20°, and 40°; Acapella by dial setting).	For all experimental conditions, there were small but statistically significant differences between devices for mean pressure, pressure amplitude, and frequency. Both devices produced similar pressure waveforms at the medium flows. At 5 L/min, the Acapella produced a more stable waveform with a lower frequency, higher amplitude, and a slightly wider range of PEP than the Flutter.

This table presents condensed versions of the information in each article without interpretation of the content.
PEP = positive expiratory pressure

Table 3. Brand Name and Manufacturer of the Included Devices

Brand Name	Manufacturer
Acapella	DHD Healthcare, Wampsville, New York
Aerobika	Trudell Medical International, Ontario, Canada
AguaPEP	PhysiotherapyDynamics, Queensland, Australia
AMBU PEEP valve	AMBU International, Ballerup, Denmark
Endo adapter	VBM Medizintechnik, Sulz am Neckar, Germany
Flutter VRP1	Axcan Scandipharm, Birmingham, Alabama
Hydrapep	Resolve Healthcare, Queensland, Australia
MiniPEP	Philips, Rüsch, Kernen, Germany
Pari PEP S	Pari, Starnberg, Germany
PEP/RMT	Wellspect HealthCare, Mölndal, Sweden
PiPEP	Koo Medical Equipment, Hong Kong, China
RC-Cornet	R Cegla, Montabaur, Germany
Resistex PEP	Mercury Medical, Clearwater, Florida
Shaker	POWERbreathe, Southam, England
System 22-PEP	Spiropharma, Klampenborg, Denmark
Therabubble	Physiotherapy Innovations, Queensland, Australia
Threshold PEP	Philips Respironics, Bend, Oregon
Vital Signs PEEP valve	Vital Signs, Totowa, New Jersey
vPEP	D R Burton Healthcare, Farmville, North Carolina

We identified 3 articles that evaluated the PEP/RMT mask, Pari-PEP system, System 22-PEP, and Resistex.[11,13,25] In the study by Christensen et al,[11] several tests were performed in 3 PEP systems with orifice diameters ranging from 1.5 to 5.0 mm during constant expiratory flows of 3–150 L/min. Dagan et al[13] tested the Resistex with expiratory flows of 10–80 L/min and expiratory volumes of 400–2,000 mL. The achieved pressure was found to be related to flow, and the pressure increased with increasing flow.[11,13] Sehlin et al[25] evaluated flow during breathing with a PEP/RMT mask with a resistance providing an expiratory pressure of 10 cm H_2O connected to an air flow transducer. The authors concluded that when expiration initiates there was no delay (ie, 0.04 s) until the expiratory flow started and pressure increased. The mean pressure during expiration was 8.6 cm H_2O, and end-expiratory pressure was zero.[25]

Pressure-Regulated (Threshold) PEP-Devices

Pressure-regulated devices have different types of valves that the expiratory pressure must overcome for the valve to open and for exhalation to begin. The valve remains open until the pressure drops under the targeted level, at which point the valve closes and no more air can be expired. The devices consist of a plastic cylinder and a valve that is subjected to different loads using a metal spring (Threshold PEP, Vital Signs PEEP valve, and AMBU PEEP valve). The resistance is adjustable by tightening the spring to create pressure on the valve.

We identified 2 articles in which 3 different devices were evaluated: Threshold PEP, Vital Signs PEEP-valve, and AMBU PEEP-valve.[11,18] The 2 PEEP valves are originally designed for mechanical ventilation and are also used as PEP devices. In 1 trial the pressure was tested, and it was found to increase quickly to the target pressure and then to drop again to zero at the end of the expiratory maneuver.[11] When evaluating the indicators of the pressure, it was found that some gave higher and other lower pressures than indicated. The pressure on the indicator on the device can not be trusted, however.[11]

Water-Bottle PEP

Expiring through a tube inserted in a bottle of water (ie, water-bottle PEP or bubble-PEP) is a simple and inexpensive device for performing breathing exercises. There are also commercially available water-bottle PEP devices such as AguaPEP, Hydrapep, and Therabubble. The resistance is given by the water and, when exceeded, bubbles are created; these bubbles in turn move the water and create the oscillations. The column of water corresponds to the unit level of pressure (cm H_2O). The system is pressure-regulated (ie, the patient must exhale until the pressure exceeds the resistance of the water column). In addition, expiration through the moving water creates oscillations. The resistance in the device is not only dependent on the water column but also on the length and inner diameter of the tube, as well as where the air release is positioned (see section on tube parameters).

We identified 5 articles that evaluated the technical aspects of water-bottle PEP.[11,19,23-25] Christensen et al[11] tested pressure when expiring through a tube with an inner diameter of 22 mm inserted in an empty jar; when the jar was filled with up to 20 cm H_2O, the pressure achieved was close to the expected levels irrespective of flow (ie, 3–60 L/min). In the study by Sehlin et al,[25] pressure during a breathing cycle was evaluated when expiring into a bottle with 10 cm H_2O connected to an air flow transducer to measure pressure. The expiratory phase began with a zero-flow period of 0.39 s before exhalation started, a time during which the airway pressure increased to 11.9 cm H_2O. Mean pressure during expiration was 11.7 cm H_2O, and expiratory pressure remained at 9.5 cm H_2O to the end of expiration.[25]

Mestriner et al[19] evaluated the design of the bottle and reported that an opening of $\geq$ 0.8 cm was needed to not affect the pressure. Santos et al[23] evaluated pressures at the end of the expiration and oscillation frequencies generated when a range of flows was applied to 5 water-bottle PEP devices. Expiratory pressures and oscillation frequencies were tested during flows of 5–25 L/min in 5 devices: 2 therapist-made water-bottle PEP devices with a tube with inner diameter of 10 mm (filled with water to 13 cm or 10 cm,

with the tube inserted 3 cm from the bottom vs at the bottom of the bottle), the AguaPEP, the Hydrapep, and the Therabubble devices, all with water to the 10-cm mark on the bottles. All devices produced similar oscillation frequencies. The therapist-made device with a tube positioned 3 cm from the bottom of the bottle created a lower pressure than the therapist-made device with the tube placed at the bottom (10.4–10.8 vs 10.9–12.9 cm H_2O). In the AguaPEP device, a pressure of 9.7–11.5 cm H_2O was measured; in the Hydrapep device, a pressure of 9.6–10.7 cm H_2O was measured; in the Therabubble device, a pressure of 8.6–12.8 cm H_2O was measured. The authors concluded that the therapist-made device filled with water to 13 cm and with the tube inserted at 3 cm above the bottom of the bottle maintained the most stable pressure throughout the tested range of flows.[23]

In another study, the same research group[24] evaluated oscillation frequencies generated in the therapist-made bubble-PEP device filled with water to 13 cm and with the tube ending 3 cm above the bottom of the bottle, which produced a resistance of 10 cm H_2O combined with tubes with inner diameters of 2–10 mm, tube length of 30 cm, and with flows of 5–25 L/min. The authors reported that the device with a tube with an inner diameter of 10 mm generated the most stable PEP relative to water height, irrespective of flow, compared to tubes with smaller diameter. The oscillation frequencies generated at all tested flows and tube diameters were between 13 Hz and 19 Hz.[24]

Oscillating PEP Devices

There are several different devices on the market that provide oscillating PEP. The Flutter and Shaker devices consist of a pipe-like mouthpiece that ends in a cone where a steel ball moves up and down. The expiratory air provides the pressure that temporarily lifts the heavy ball vertically, and some air is let out through a perforated lid. A certain pressure must be reached and maintained for the ball to oscillate. Acapella creates oscillation using a valve that repeatedly interrupts air flow, resulting in oscillating PEP. The valve is designed with a counterweight and a magnet to achieve the desired repeated closing and opening of the resistance. Different models are available for patients with different flow capacities. The RC Cornet consists of a bent plastic tube with a mouthpiece and a soft tube inside. By exhaling through the device, the soft tube flutters and strikes the inner walls of the hard tube, which creates oscillating PEP. Both the Aerobika and the vPEP devices have flapping valves that provide oscillation during exhalation. Most devices can be adjusted to influence average expiratory pressure, oscillation frequency, and oscillation amplitude.

We identified articles that evaluated a number of oscillating PEP devices: the Flutter device (7 articles), the Acapella Choice, DM, or DH devices (7 articles), the Aerobika device (3 articles), the Shaker device (1 article), the RC Cornet device (1 article), and the vPEP device (1 article) (Table 2).[7,8,10,14,15,17,20,22,26,27] We noted a correlation between flow and expiratory pressure as well as between expiratory pressure and oscillation frequency and amplitude.[7,8,10,14,17,20,22,26,27] The mechanical behavior of these oscillating PEP devices has both similarities and differences (Table 2).[15,17,22,26,27]

Both the material and the shape of the ball in the Flutter device have an impact on the results; the original stainless steel ball produced the highest pressure ($>$ 80 cm H_2O) at air flows $>$ 180 L/min.[14] Due to the design, gravity has an impact on the result. The angle at which the device is positioned also affects the pressure and oscillation provided: a positive angle (+10° to +40°) produced higher pressure, oscillation frequency, and flow amplitude compared to when the device was held at 0°; a negative angle (–10° to –40°) produced lower pressure, oscillation frequency, and flow amplitude compared to 0°.[7,10]

Resistors

A variety of PEP devices provide interchangeable resistors to generate the resistance. The design and diameter of the resistors as well as the expiratory flow govern the resistance that is given. Resistor designs differ, but all have a fixed and defined diameter of the opening through which the air passes, which in the devices tested in the trials vary from 1.0 mm to 7.0 mm.

We identified 2 studies in which resistors were tested.[16,21] Both included various resistors with different designs, and the differences were reported to affect the pressure generated.[16,21] In one of the studies, valves or conical resistors with inner diameters of 5–7 mm were tested with flows of 0.2–1.5 L/min.[21] For a given flow, pressure decreased as the inner diameter of the orifice increased; the pressure also decreased as the length of the resistor decreased. Among the valves tested, pressure quickly rose as flow velocity increased; the smaller diameter (5 mm in this case) generated the maximum resistance most quickly, while the resistance at both 6 mm and 7 mm was associated with a flatter rise in the resistance curve. The conical resistor created almost the same pressure, though at slightly higher flows.[21]

In the other study, resistors from different manufacturers were tested at the constant flows of 10 and 18 L/min.[16] The study included resistors in the RMT/PEP set, PiPEP, Mini-PEP, and the 15-mm endo-adapter, and the tested resistors had diameters of 1.5–5.0 mm. The tests showed a significant difference in the resistance created by resistors from the various manufacturers, despite the same diameter of the opening. There were some differences in the resistor designs: the Mini-PEP resistor is conical inside and is

slightly longer, and the resistor from the 15-mm endoadapter is longer than some of the other tested models. The authors concluded that one should not use a resistor in a device for which it is not designed.[16]

Mask/Mouthpiece

PEP devices may be used with a mask or mouthpiece. There are several different types on the market in a variety of sizes and made of various materials. One trial has evaluated the various aspects of a standard mask (ie, size 5) and mouthpiece used with the PEP/RMT set valve.[12] Dead space was tested with water and pressure during constant flows. The dead space volume was 170 mL in the mask and 26 mL in the mouthpiece. The use of a mouthpiece achieved significantly higher pressures compared with the mask. To assess the degree of leakage from the device, 40 patients undergoing abdominal surgery were treated with these components. Eight of the patients who used the mask and 9 who used the mouthpiece were not able to perform the exercises without leakage on the first postoperative day, but technique gradually improved during hospital stay.[12]

Valves

The design of the valves used in PEP devices also has an impact on the pressure generated. We identified 1 article that evaluated flow-generated properties of various valves (ie, PEP/RMT set, System 22-PEP and Pari-PEP).[11] Expiring through the valves without adding any resistance resulted in a positive expiratory pressure of 2.6 cm H_2O (PEP/RMT set), 0.5 cm H_2O (System 22-PEP), and 0.9 cm H_2O (Pari-PEP) at flows of 3–150 L/min.[11]

Length and Diameter of Tubes

PEP may be created by solely expiring through a tube, which may also be a part of a blow-bottle device. We identified 4 studies that evaluated diameter and length of tubes for PEP solely or as part of a water-bottle PEP device.[9,19,21,24] In the study by Boden et al,[9] expiring through a tube with an internal diameter of 4 mm with various lengths (40–120 cm) was tested at flows of 4–11 L/min. A positive linear relationship between pressure and flow was noted across the different tube lengths up to 120 cm at flows of 4–11 L/min. In addition, a regression model for estimation of pressures generated with a flow of 20 L/min was presented.[9]

The relationship in pressure achieved between length and inner diameter of a tube inserted in water has been tested by Mestriner et al[19] and Santos et al.[24] Mestriner et al[19] reported that, at low flow, the pressure was about 10 cm H_2O; however, an increase in expiratory flow rapidly raised the pressure when using a tube with an inner diameter < 8 mm. A tube inner diameter of 4 mm with a length of 40 cm resulted in a pressure of 40 cm H_2O. The authors concluded that a tube with an inner diameter of ≥ 8 mm does not affect the pressure in tubes ≤ 80 cm and is advisable to use.[19]

Santos et al[24] evaluated how the use of tubes with an inner diameter of 2–10 mm affects pressure at flows of 5–25 L/min inserted in a water column of 10 cm. At flows of 5 and 10 L/min, the measured pressures in the 2-mm tube were 20.1 and 41.8 cm H_2O, respectively. At flows of 5 and 25 L/min, the pressure dropped when the inner diameter increased. A pressure of approximately 10 cm H_2O was observed when utilizing a tube with an inner diameter of 5 mm at a flow of 5 L/min and a tube with an inner diameter of 10 mm at a flow of 25 L/min. The 10-mm tube generated the most stable PEP in relation to water height (in this case, 10 cm), irrespective of flow.[24]

In the study by Phimphasak et al,[21] different resistors were tested regarding pressure-flow relationship. Conical resistors with lengths of 1–4 cm but with the same orifice of 5 mm were evaluated. The tests revealed that as the resistor's length increased at a given flow, the pressure increased.[21]

Blow Glove

When there is a lack of available equipment or devices, other solutions are invented. As with expiring solely through a tube, it is possible to create resistance while blowing into a latex glove (ie, a "blow glove"). Techniques include releasing the air from the glove after each expiration (ie, inflate the glove from zero with each breath), or gradually expanding the glove with each expiration to increase resistance.

We identified 1 trial that investigated the pressure achieved while expiring in a blow-glove device, with each expiration starting from zero, and compared it to the Resistex PEP device.[13] The blow-glove device was evaluated using 2 sizes of latex gloves, which were powdered or powder-free. The blow-glove device produced a significantly higher pressure in the "recommended range" than the Resistex device. No significant difference was observed between the glove sizes, but the powdered latex glove showed a significantly higher range of PEP than the powder-free latex glove.[13]

Discussion

PEP and oscillating PEP are incorporated in clinical practice for many groups of patients in many countries. The treatment can have different aims, and the physiological explanation behind its effect has been explored in an earlier publication from our research group.[3] PEP can be used in

a variety of ways, to optimize lung volumes (both to increase it in groups of patients with reduced lung volumes due to surgery or immobilization and to decrease it for patients with hyperinflation, such as patients with COPD), to facilitate mucus clearance as a part of PEP cycles, and to increase muscle strength with respiratory muscle training. The treatment must be prescribed accordingly. Prescriptions with individualized instructions on how to perform the PEP breathing technique, how often and when, have a major impact on the outcome.[3] Another important aspect is the choice of device or equipment to be used. This article's aim was to present the current knowledge on the technical aspects of these devices.

PEP is often provided by flow-regulated or pressure-regulated devices. These have several similarities as well as key differences. The flow-regulated devices allow flow immediately and constantly,[25] and the pressure achieved is correlated to the expiratory flow.[11] A limitation is that it is difficult to both teach and learn the optimal technique in terms of how fast and how much to exhale. To standardize the technique, the expiratory pressure needs to be measured with a manometer connected to the device. The pressure-regulated devices have a targeted pressure that must be achieved before expiratory flow can start.[11] As a result, expiration starts and ends with periods of no flow, which leads to a specific breathing rhythm. The selection of the right system to use for a given patient depends on the aim of the breathing exercises and on the patient's capacity.

When using water-bottle PEP, it is important to understand how tube length, inner diameter, and the design of the bottle may affect the resistance and achieved PEP. To avoid mistakes when instructing a patient, these parameters may be of importance to adjust the patient's flow correctly during expiration. The smaller the inner diameter of the tube or the outlet, the greater the resistance; similarly, increasing tube length increases resistance.[19] A far-too-narrow tube may cause dizziness or exhaustion. In clinical practice, tubes intended for other purposes, such as suction, could cause respiratory demands that are too great for the patient. An inner diameter of $\geq$ 8 mm has been recommended.[19]

In the study by Sehlin et al,[25] in which they compared the PEP/RMT mask and water-bottle PEP device, the authors reported that the use of the latter was associated with a zero-flow period just before expiration. Sehlin et al[25] concluded that patients may not have the stamina to take as many breaths when using a water-bottle PEP device as when using a PEP/RMT mask. This is probably because the patients must achieve a predetermined pressure for each expiration to overcome the threshold with the water-bottle PEP device before expiratory flow can occur.[25] One may speculate that this device could keep the airways open over a longer period, which could make this a more effective method to open peripheral airways, but this hypothesis must be further investigated. It may be easier for the physiotherapist or respiratory therapist to regulate resistance in threshold-regulated devices compared with flow-regulated devices.

The oscillating PEP devices presented in our review differ substantially from one another in design as well as in performance. For example, the oscillations vary considerably in frequency, as does the pressure achieved, making it a challenge to select the correct setting of the desired pressure. In addition, the Acapella comes in different versions (ie, one of them is intended for patients who are unable to achieve an air flow $>$ 15 L/min). The set pressure and oscillation frequency may vary within each device.[8] A limitation of the Flutter device, which may be an advantage in certain scenarios, is that it is position-dependent; the user is expected to regulate the resistance by altering the angle at which the device is positioned. This is likely to be difficult for many patients to handle by themselves. Patients must be aware of the physiological aim with the treatment and must be trained and repeatedly evaluated to utilize the Flutter optimally on an ongoing basis.

It is important for clinicians to be aware that the pressure achieved with different resistors varies across manufacturers, even when the diameters of the orifices are the same. These variations are due to the design of the resistors, including length and interior shape; for example, one resistor is conical on the inside.[16] The problem is that these different products can be easily mixed up because the color coding of the resistors may be the same and the outside diameter is the same; in other words, the components fit. As a result of this confusion, the therapist may not be aware of the actual resistance to which the patient is exposed if a resistor is replaced with one from another manufacturer.[16] Regardless of the manufacturer of the system, it is important to be consistent with choice of brand to ensure a correct PEP for the patient.

The study by Clase Larsson et al,[12] in which the authors compared flow resistance using the resistor with a mask or a mouthpiece, reveals that there is a learning curve for patients regarding both mask and mouthpiece, as demonstrated by the fact that there was greater expiratory leakage on day 1 than on day 5 and the leakage was greater with the use of the mask than with the use of the mouthpiece. Moreover, the pressure achieved at a given flow was generally higher when using the mouthpiece than when using the mask.[12] For a patient who can cooperate fully, the mouthpiece may be the optimal choice for patients with low tidal volumes. On the other hand, for patients who cannot follow instructions, it is preferable to use a mask.

Tube length and inner diameter are also important to consider when such are used. An inner diameter $<$ 8 mm raised the resistance, exponentially so when the tube was lengthened.[19] In a water-bottle PEP device, it is therefore important to focus not only on the water column and the design of the bottle but also on which tube to use.

As PEP and oscillating PEP devices may be expensive, it is common to create cheaper equipment. The water-bottle

PEP device is such a solution, often created from leftover bottles and tubes that are easily accessible in the hospital. Another low-cost, therapist-made device is composed of a tube with a latex glove. We found 1 article that evaluated technical aspects of blow-glove devices, both with and without powder and in 2 glove sizes, where each expiration restarted with the glove at zero.[13] The results indicated differences between the gloves, but as many types of gloves may be used in health care facilities, it is not possible to generalize their results to other brands of gloves. In addition, the specific reasons for using a glove were not explained.

During the COVID-19 pandemic, it has become more evident that the virus may be spread during breathing exercises and inhalations. In this review, even though we did not search for this outcome, none of the articles we identified included specific information concerning the dispersion of aerosol and droplets. Future trials must be undertaken to study the risk of spreading the virus, and, when new devices are developed and old ones renewed, this must be taken under consideration to avoid contagion during use.

Structured literature searches were conducted in relevant databases to ensure that all relevant studies were included. In addition, reference lists and eventually studies earlier known by the authors were included. The searches revealed 21 articles since 1995, of which one was published before 2000, 8 between 2000 and 2010, and 12 thereafter. The studies had been performed in different parts of the world, but some countries are more representative than others, such as Australia, Brazil, the United States, and Sweden. Even though we found some evidence concerning technical views that is of interest for us when choosing devices for clinical use, much is still unknown. Further trials evaluating and comparing different equipment are therefore needed.

Limitations

It is a challenge to find articles when searching through databases. A strength of this review is that, to increase the likelihood of finding the articles we were searching for, we performed the searches with an experienced librarian. Even though the articles are heterogeneously indexed, which subsequently leads to difficulties when performing literature searches, some articles were published in journals not included in the defined databases or were written in other languages than English. It is therefore not known whether the articles we identified cover the entire field comprehensively, which is a limitation. Another limitation is that we did not perform any quality assessment of the included articles. There are several evaluation tools for performing methodological evaluations, such as PEDro or GRADE for randomized controlled trials, but to our knowledge there are no tools for evaluating experimental trials, such as the studies discussed in this review. This is a limitation, although we describe possible sources of bias to increase external validity. There are also other devices and equipment used in the world. No evaluations of these devices were found during the literature search, which may indicate that there are no studies on those devices or that there were gaps in our search strategy.

Conclusions

In this review, we provide technical aspects of devices and equipment used for breathing exercises with PEP and oscillating PEP to provide a better understanding of the technology, which we hopes will make it easier to provide optimal levels of pressures, flows, and achieved effects on lung volume for patients when using different devices. The performance of PEP and oscillating PEP devices and their technical details are varied and adjustable, which is important to consider when prescribing breathing exercises and deciding which device to use. Further investigation is needed to determine whether there are different devices or equipment that would better suit a specific patient group or a specific goal to further improve the effects of PEP treatment.

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REFERENCES

1. Falk P, Eriksen AM, Kølliker K, Andersen JB. Relieving dyspnea with an inexpensive and simple method in patients with severe chronic airflow limitation. Eur J Respir Dis 1985;66(3):181-186.
2. Lumb AB. Compensation for increased resistance to breathing, in Lumb AB, Nunn JF, Pearl RG, editors. Nunn's Applied Respiratory Physiology, 5th edition. Edinburgh: Elsevier Butterworth-Heinemann; 2000:73-74.
3. Fagevik Olsén M, Lannefors L, Westerdahl E. Positive expiratory pressure – common clinical applications and physiological effects. Respir Med 2015;109(3):297-307.
4. Fagevik Olsén M, Westerdahl E. Positive expiratory pressure in patients with chronic obstructive pulmonary disease – a systematic review. Respiration 2009;77(1):110-118.
5. McIlwaine M, Button B, Nevitt SJ. Positive expiratory pressure physiotherapy for airway clearance in people with cystic fibrosis. Cochrane Database Syst Rev 2015(6):CD003147 No.
6. Orman J, Westerdahl E. Chest physiotherapy with positive expiratory pressure breathing after abdominal and thoracic surgery: a systematic review. Acta Anaesthesiol Scand 2010;54(3):261-267.
7. Alves LA, Pitta F, Brunetto AF. Performance analysis of the Flutter VRP1 under different flows and angles. Respir Care 2008;53(3):316-323.
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. Boden IJ, Reeve J. Phase 1 evaluation of tubing PEP as an improvised positive expiratory pressure device: pressures generated through oxygen tubing across a range of flow rates and lengths. Pulmonol Respir Res 2017;5(1):1-6.

10. Brooks D, Newbold E, Kozar LF, Rivera M. The flutter device and expiratory pressures. J Cardiopulm Rehabil 2002;22(1):53-57.
11. Christensen EF, Jensen RH, Schønemann NK, Petersen KD. Flow dependent properties of positive expiratory pressure devices. Monaldi Arch Chest Dis 1995;50(2):150-153.
12. Clase Larsson S, Fagevik Olsén M. An evaluation of positive expiratory pressure using mask and mouthpiece. Adv Physiother 2006;8 (3):116-121.
13. Dagan Y, Wiser I, Weissman O, Farber N, Hundeshagen G, Winkler E, et al. An improvised "blow glove" device produces similar PEP values to a commercial PEP device: an experimental study. Physiother Can 2014;66(3):308-312.
14. de Lima LC, Duarte JBF, Lepore Neto FP, Abe PT, Gastaldi AC. Mechanical evaluation of respiratory device. Med Eng Phys 2005;27 (2):181-187.
15. 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.
16. Fagevik Olsén M, Carlsson M, Olsén E, Westerdahl E. Evaluation of pressure generated by resistors from different positive expiratory pressure devices. Respir Care 2015;60(10):1418-1423.
17. 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.
18. Matsuo PY, Yanagisawa PY, Cahalin PL. Brief research report: the feasibility of expiratory resistive loading using the threshold inspiratory muscle training device. Cardiopulm Phys Ther 2014;25(3):92-95.
19. Mestriner RG, Fernandes RO, Steffen LC, Donadio MVF. Optimum design parameters for a therapist-constructed positive-expiratory-pressure therapy bottle device. Respir Care 2009;54(4):504-508.
20. Mueller G, Bersch-Porada I, Koch-Borner S, Raab AM, Jonker M, Baumberger M, Michel F. Laboratory evaluation of four different devices for secretion mobilization: acapella choice, green and blue versus water bottle. Respir Care 2014;59(5):673-677.
21. Phimphasak C, Ubolsakka-Jones C, Jones DA. Design and function of a new conical positive expiratory pressure device to be used during exercise. Respir Care 2018;63(8):966-980.
22. Pursley D. Analysis of three oscillating positive expiratory pressure devices during simulated breathing. Respir Ther 2017;12(1):52-56.
23. Santos MD, Milross MA, Eisenhuth JP, Alison JA. Pressures and oscillation frequencies generated by bubble-positive expiratory pressure devices. Respir Care 2017;62(4):444-450.
24. Santos MD, Milross MA, Eisenhuth JP, Alison JA. Tubing internal diameter affects the pressures and oscillation frequencies generated by the therapist-made bubble-positive expiratory pressure device. Physiother Theory Pract 2020;36(2):333-339.
25. Sehlin M, Ohberg F, Johansson G, Winsö O. Physiological responses to positive expiratory pressure breathing: a comparison of the PEP bottle and the PEP mask. Respir Care 2007;52(8):1000-1005.
26. Van Fleet H, Dunn DK, McNinch NL, Volsko TA. Evaluation of functional characteristics of 4 oscillatory positive pressure devices in a simulated cystic fibrosis model. Respir Care 2017;62(4):451-458.
27. 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.