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Positive expiratory pressure techniques in respiratory patients: old evidence and new insights

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None declared.

Educational aims

- To describe the rationale for the use of positive expiratory pressure (PEP) techniques as a means of chest physiotherapy in respiratory patients.
- To compare both the effectiveness and problems of the most popular PEP devices in clinical practice.
- To introduce the impact and potential interest of temporary PEP (TPEP) techniques in this field.

Summary

In recent years, a large number of PEP devices, used to assist in airway clearance or, at the very least, to allow for effective self-administered physiotherapy, have been developed. A secondary clinically relevant objective of these devices is to prevent recurring infections and atelectasis, or to improve pulmonary mechanics and facilitate gas exchange, thus lowering the impact of disease progression. The use of PEP devices in this field has become widely accepted for two main reasons: 1) their clinical efficacy, which is as great as that of conventional chest physiotherapy practice, and 2) the high level of acceptance and compliance by patients, which makes PEP devices very useful in the domiciliary environment. The functional and clinical response of any specific PEP device, with or without vibration effect, may vary according to a specific diagnostic group. Ultimately, the choice of airway clearance strategy may be the one that is clinically effective, cost-effective and preferred by the patient and which, therefore, supports adherence. Recent technology has enabled the development of a new machine, which is able to apply a TPEP at a level several times lower than that applied with previous devices; thus, at least potentially, it is able to reduce the risk of mechanical stress injury to the bronchial tree and lung parenchyma. In this review, we will discuss the rationale for the use of PEP devices and compare both their effectiveness and problems in clinical practice. Finally, we will introduce the application and potential interest of TPEP as a new means for treating patients with hypersecretion.

Over the past few years, the terms airway clearance and chest physiotherapy were synonymous with manual percussion, postural drainage and vibration (the so-called manually assisted breathing techniques (MABT)). Identification, through scientific research, of the vital role of secretion removal in managing several diseases with impaired mucociliary clearance and cough (*e.g.* chronic bronchitis, bronchiectasis, cystic fibrosis (CF), ciliary diskinesia and neuromuscular disorders), has led to the development of a large number of devices used to

HERMES syllabus link: modules B.1.2–4, B.1.6, E1.14, A1.3, H4

assist in airway clearance or, at the very least, to allow for effective self-administered physiotherapy. Furthermore, a secondary clinically relevant objective of these devices is to prevent recurring infections and atelectasis, or to improve pulmonary mechanics and facilitate gas exchange, thus lowering the impact of disease progression in the individual patient and/or improving morbidity and complication rate in those individuals recovering from thoracic or abdominal surgery [1].

Despite the level of evidence in using several devices dealing with assisted airway clearance varying according to different diseases, there is now a large consensus on the wide application of such a form of chest physiotherapy in the clinical practice, over and above the adoption of classical MABT [2], especially for those patients showing a valid cough reflex and who are affected by CF.

This educational overview provides a specific look at the classical PEP techniques that were developed to assist patients in their airway clearance both without (PEP) and with airway vibrations and oscillations (oscillatory PEP (OPEP)). In addition, the impact and the potential role of TPEP, a new and useful technique in this clinical field, will be introduced. We will not deal with different pressure techniques such as intermittent positive pressure breathing, intrapulmonary percussive ventilation or noninvasive mechanical ventilation, which are more commonly used to promote and assist airway clearance in different clinical conditions referring to special care [3] and acute care interventions [4].

PEP techniques: rationale and clinical application

Following its first application in Denmark, PEP was applied as a high-pressure technique interfaced *via* a face mask as an adjunct to traditional MABT in respiratory patients [5]. PEP devices have now been modified to allow for the patient interface to consist of either a face mask or a mouthpiece. The traditional main components of the device consist of a one-way valve connected to either a small exit orifice or, more commonly, an adjustable expiratory resistor. A manometer is incorporated into the system between the one-way valve and the resistor to measure the level of applied expiratory pressure. Tightening the expiratory resistor decreases the ability of flow to move rapidly through the device and hence increases expiratory pressure through flow retardation. Low-pressure (5–20 cmH_2O at mid-expiration) or high-pressure (to generate 20–100 cmH_2O, which is achieved by performing a forced expiratory manoeuvre after maximal inspiration) PEP devices can be used with the assistance of a respiratory therapist or caregiver, and even independently by the patient after the patient receives appropriate instruction and does a return demonstration to the instructor. The duration and frequency of treatment should be tailored for each individual, mainly based on the response to airway clearance therapy. The "blow bottle" is still used as the most economical device available in the clinical practice which surrogates the PEP effect.

The theoretical benefit of PEP is the ability to enhance and promote mucus clearance by either preventing airway collapse by stenting the airways [6] or increasing intrathoracic pressure distal to retained secretions, by collateral ventilation or by increasing functional residual capacity [7]. The use of the OPEP technique was first described in Switzerland [5]; it combines the above reported benefits of PEP with airway vibrations and/or oscillations. Three devices are currently available on the market: Flutter, Acapella and Quake.

The Flutter is a pipe-shaped handheld device which contains (inside the bowl of the "pipe") a heavy stainless steel ball that sits in a circular cone covered by perforations that allow expiratory airflow to pass through. The basic operation of the Flutter occurs when expiratory flow through the mouthpiece causes the ball to rise and fall within the cone, which creates a PEP effect of between 5 and 35 cmH_2O. These vibrations range 8–26 Hz [8]. The Flutter bowl must be pointed upward for maximum efficacy and proper operation.

The Acapella uses a counterweighted plug and magnet to create airflow oscillations during sustainable expiratory flow (>15 or <15 L per min, according to models). Acapella's performance does not depend on device and/or patient orientation, thus it may be easier to use for some patients, particularly at lower expiratory flows. However, a bench study comparing Acapella with Flutter concluded that both devices have similar characteristics in the operating level of pressure amplitudes and frequencies [9].

The Quake is also a pipe-shaped device with a manually operated rotating handle that creates the oscillations on the bowl. The frequency of oscillation is, therefore, controlled by how quickly the handle is rotated. Rotating the handle slowly creates a low-frequency oscillation and a higher

expiratory pressure. Rotating the handle quickly provides high-frequency oscillations and a lower expiratory pressure.

The theoretical benefits of OPEP have been described as a two-fold increase in airway clearance [1, 5]. Indeed, oscillations decrease the viscoelastic properties of mucus plugs, which make them easier to mobilise and create short bursts of increased expiratory airflow that assist in clearing secretions [10]. Secretion removal is then facilitated by deep exhalations through the device or by subsequent coughing techniques. Figure 1 shows the most widely and commonly used devices based on the PEP principle to assist airway clearance in adults with a normal cough reflex.

Most studies using low-pressure or high-pressure PEP have been performed in patients with CF. These studies demonstrated that PEP therapy may improve pulmonary function status and may facilitate secretion removal; however, the results achieved were not different from those obtained with other airway clearance techniques or devices [1]. The most important effect was the significantly higher amount of sputum obtained with PEP than with other study comparators, and some improvement in lung function [11]. However, due to the relatively small number of patients included, these results are still too few to provide a scientific conclusion leading to a firm indication.

The use of PEP in diseases other than CF (chronic bronchitis, post-operative patients, severely disabled individuals and HIV) has conflicting results [1]. Overall, PEP caused no significant differences in the outcomes studied, apart from better compliance compared with other techniques in post-operative patients [12]. PEP had little and short-term (assessed by 1-month follow-up) effects in patients with chronic bronchitis and chronic obstructive pulmonary disease (COPD) [13], whereas in another study, PEP led to a decrease in infections and exacerbations in the same patient groups [14].

The application of OPEP in patients with respiratory problems also led to similar conclusions. The reported effects (in particular the removal of secretions) in patients with CF were of similar magnitude compared with those obtained by means of PEP device application [1, 5, 8]. In different conditions, such as chronic airway obstruction, panbronchiolitis and bronchiectasis, OPEP provided a slight improvement in lung function, but no or little enhancement in mucus production [15].

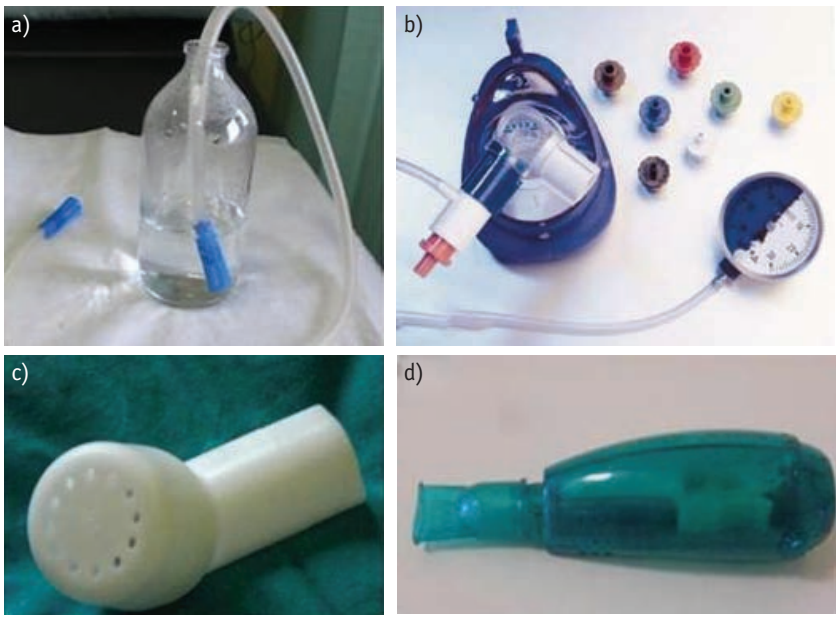

Figure 1
Most commonly used PEP devices and oscillatory techniques in clinical practice; a) blow bottle, b) PEP mask, c) Flutter and d) Acapella.

From a clinical point of view, PEP and/or OPEP devices are frequently used in daily practice with patients who are more likely to inform health professionals of their preference and compliance. Figure 2 shows the chest radiograph examinations of a single patient admitted to rehabilitation after surgery and treated with a PEP mask to assist airway clearance.

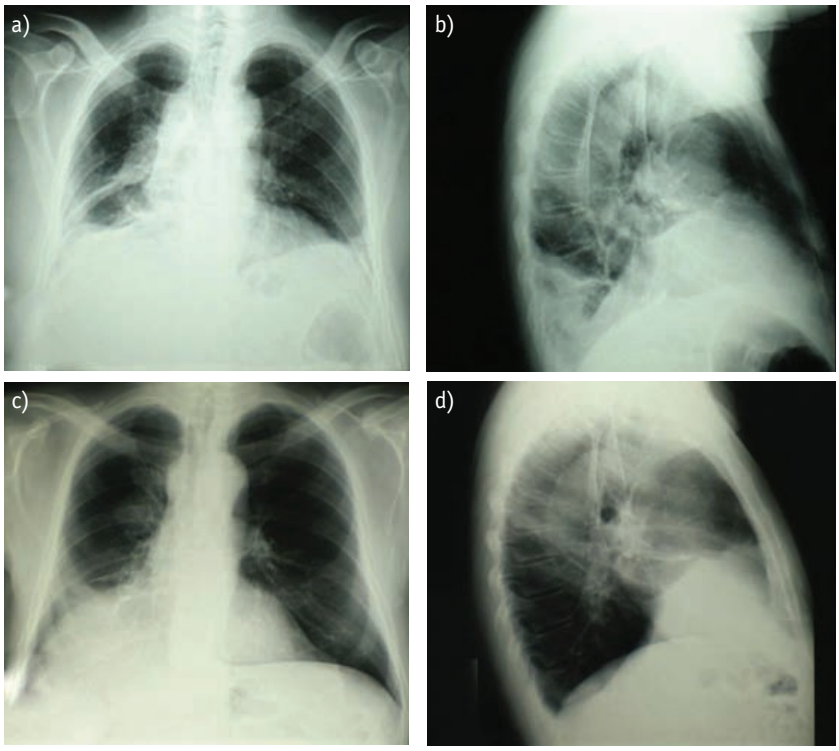

Figure 2
Chest scan sequence in a patient with sputum retention following thoraco-abdominal surgery. Anterior and lateral radiographs a) and b) before and c) and d) at discharge after PEP application. The slight atelectasis in the right lower lobe was resolved at the end of treatment.

Comparing different techniques

Due to accumulating clinical experience and the high variability of devices used, dependent both on patients' and/or professionals' preference, only a few studies have compared PEP with OPEP, most of them in patients with CF [1]. These trials included no more than 150 participants and they did not report any clinical or physiological advantage of one device over the other; only transient blood gas changes were observed with PEP use in adult patients with CF [16].

Taking all data into account, it can be concluded that PEP therapy may be as effective as conventional chest physiotherapy in promoting and improving airway clearance in patients with respiratory disorders [1, 17]. This should be of particular interest for those patients suffering from CF, since the role of PEP therapy in airway clearance for other disease populations is virtually unknown. Among the OPEP devices, Flutter therapy may have at least similar effects on sputum production and pulmonary function as do conventional secretion clearance therapies. Therefore, from an evidence-based perspective, while PEP and OPEP did not definitively prove superiority to other airway clearance strategies, there was no clear evidence that they were inferior. Indeed, both devices appeared to be at least equivalent to other airway clearance strategies. Moreover, a practical and recurrent aspect in most of the clinical trials investigating the effectiveness of PEP and OPEP devices is a reported patient preference for these devices when compared with usual MABT [1, 17], most likely because PEP and OPEP are more convenient and less time consuming. Ultimately, the choice of airway clearance strategy may be the one that is clinically effective, cost-effective and preferred by the patient and which, therefore, supports adherence.

TPEP: from physiology to bedside

Given the fact that excessive airway secretion could be practically managed using a variety of different but similarly effective methods of airway clearance [18], the importance of understanding the physiological principles by which many of these techniques behave or may behave is apparent [19]. One of the over-riding principles of most of the currently available techniques is that they apply high pressure to the airways, the theory being that in disorders where hypersecretion is relevant or prevalent, the high applied airway pressure may aid in mucus clearance by creating pressure behind the mucus blocking the airway. Thus, when combined with a normal cough reflex, the patient is able to enhance his/her clearance of the mucus.

In the peripheral lung, where mucus plugs may block off small airways and hence prevent normal ventilation of the alveolar gas exchange units, air movement may occur *via* the pores of Kohn, small holes within the alveolar wall which allow the movement of air between the alveolar spaces, referred to as collateral ventilation [20, 21]. In patients with no airway damage, collateral ventilation probably does not occur as the resistance to air movement between alveolar spaces is too great. By contrast, in damaged airways, the resistance to airflow through alveoli is considerably reduced, thus facilitating the movement of air *via* the collateral route [22].

The other important factor that may favour an individual's airway clearance is the use of an oscillatory frequency, which can alter the viscoelastic and/or shearing properties of mucus. Mucus clearance is directly proportional to the depth of the mucus, and is inversely proportional to its viscosity and elasticity. If the oscillatory frequency is ~13 Hz, there is potential to change the viscoelastic properties of mucus and hence improve mucus transport [18]. If higher frequencies are used, this may effect the airways directly because airways can vibrate, further aiding the loosening of mucus and promoting clearance. The precise frequency required for this effect is still unclear.

Recently, a new modality for the delivery of PEP through the mouth during spontaneous breathing, called TPEP, has become available to achieve such combined effects in patients with problems due to hypersecretion. To date, the effect of continuous application of PEP to the airway of normal individuals at the level of 15 cmH_2O has been shown to produce a 20% increase in functional residual capacity, as assessed by constant volume whole body plethysmography [23]. TPEP causes a slight increase of pressure in the respiratory airways during the respiratory cycle (+1 cmH_2O), which is interrupted before the end of the expiratory phase (figure 3). This immediately reduces the pressure of the airways and assists in the drainage of mucous and secretions in the upper airways.

This level of applied pressure is, therefore, several-times lower that those commonly applied

with other PEP and OPEP devices. An expiratory pressure ≤1 cmH_2O applied only for a fraction of the expiratory phase, since the instrument is equipped with a suitable exhalation valve, may improve the distribution of alveolar ventilation. Indeed, it has been experimentally shown that the difference in the alveolar pressure is of this order of magnitude (*i.e.* 1.5 cmH_2O) [24]. At this pressure level no mechanical stress injury is likely to be expected in the bronchial tree or lung parenchyma. The TPEP machine is also supplied with an aerosol chamber for liquid drug distribution, and a spacer unit for multiple drug injectable therapy. TPEP therapy has been advised for continuous use over 15–20 min, during spontaneous breathing, twice per day.

However, the prerequisite for applying TPEP is still a normal cough reflex and competence of the individual patient. Thus, TPEP must be clearly incorporated among other PEP devices commonly used to clear secretions as a means of physiotherapy. In figure 4, a representative individual connected with the machine while using TPEP is illustrated.

To date, the clinical application of TPEP is still limited and, above all, it is not absolutely clear whether different underlying diagnosis may affect indication for its use. TPEP works by detaching and removing secretions from the peripheral airways, and can increase the deposition of aerosolised drugs deeper into the lungs by ~30%, compared with more traditional systems [25].

The preliminary and experimental use of TPEP in pathology has been performed in chronic respiratory diseases, including COPD, asthma and CF; it has been shown that symptoms and pulmonary function testing (including reduction in air-trapping) improved after 2 weeks of treatment [25]. In addition, TPEP has been used for 30 min twice daily for 5 days in the preparation of 28 COPD patients for major abdominal surgery [26]. The results showed that there was less inhomogeneity, improved lung ventilation and significant changes in arterial blood gases, whereas patients reported a significant reduction in mucus and in perceived dyspnoea. Figure 5 displays images of dynamic ventilation obtained in one representative patient over 30 min during TPEP therapy.

Overall, experimental results suggest that TPEP deserves further study and attention in future clinical research. In particular, it might have an important role in the treatment and rehabilitation of patients with chronic respiratory diseases for the following reasons.

1) TPEP effectively drains secretions; this is useful for those resistant to traditional mucolytic and drainage interventions.

2) TPEP leads to a clinically relevant improvement in respiratory symptoms, which could be of particular interest to those patients suffering from COPD, bronchiectasis and CF, in whom accumulation of secretions in the airways substantially contribute to debilitating symptoms.

3) TPEP causes a rapid improvement of pulmonary function, characterised by a reduction in the degree of pulmonary hyperinflation and a concurrent physiological redistribution of pulmonary volumes (reduction in residual volume and increase in relaxed vital capacity), and of ventilation distribution.

4) TPEP may lead to the reduction of interventions for clearing secretions and/or the necessity of cycles of pharmacological prophylaxis of respiratory infections.

An ongoing clinical trial, limited to only 10 days' duration [27], aims to recruit 100 patients in two groups with chest physiotherapy (control group) or chest physiotherapy plus TPEP. The

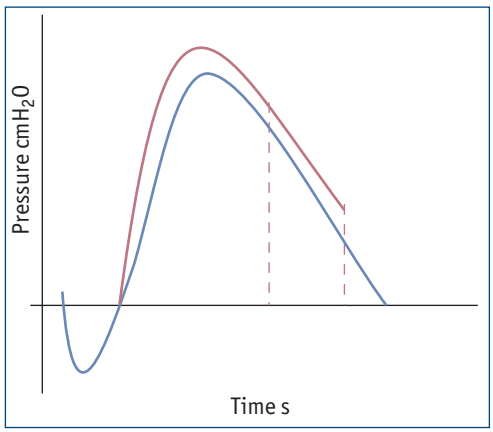

Figure 3
Trace showing the change of airway pressure during the respiratory cycle as recorded with TPEP (red) and compared with unassisted breathing (blue). Note that extra PEP is prematurely interrupted before the end of expiration.

Figure 4
One representative individual breathing spontaneously, while using the TPEP device.

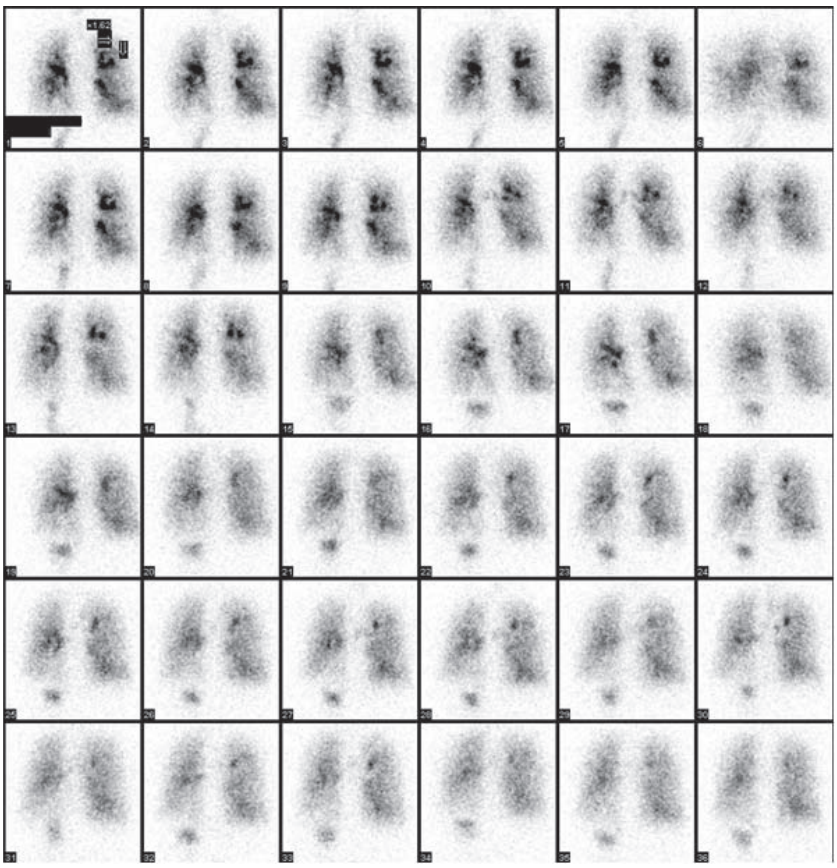

Figure 5
Dynamic ventilation as obtained with lung ventilation scintigraphy (anterior scan) over 30 min (1 frame per min) during TPEP therapy in one representative COPD patient. It can be noted that the central deposition of mucus plugs progressively clear over time. Reproduced from [26], with permission from the publisher.

study intends to determine whether TPEP provides additional benefits over conventional therapy. To date, only 47 patients have been recruited into the study and, while no conclusive analysis of data is currently possible, the results showed the following changes at 10 days: forced expiratory volume in 1 s +90 mL, maximal inspiratory pressure +5.5 cmH_2O, arterial oxygen tension +6.5 mmHg, arterial oxygen tension measured by pulse oximetry +2% and arterial carbon dioxide tension -2.5 mmHg (unpublished data). Nonetheless, mainly due to the short study period, which may not be long enough to achieve a sustained effect, the interpretation of these very preliminary data from the trial should be viewed with caution.

Several questions still remain and arise about the use and application of TPEP in a clinical environment. In addition to further consideration of cost, it seems that these questions should be answered in the future.

1) What is the optimal time frame for treatment at which the maximal effect can be achieved? What is the washout time (*i.e.* the time taken to return the patient back to the pre-use baseline)?
2) What is the time at which maximal response in a patient is achieved, with no further obvious improvement in lung function?
3) How does the outcome of TPEP compare to other currently used airway clearance techniques, most of which have little or no evidence base supporting them, but from clinical observation appear to work in some, but not all, patients?
4) Which patient groups will benefit most from this treatment?
5) Is it also applicable in children?

Conclusions

The use of PEP devices in assisting airway clearance in patients with chronic sputum and hypersecretion has become widely accepted for two main reasons: clinical efficacy that is as good as in conventional chest physiotherapy practice, and the high level of acceptance and compliance by patients, which makes PEP devices very useful in the domiciliary environment.

Several devices, with or without the vibration effect, have been tested in patients with different underlying diagnoses, showing no substantial difference when compared with each other. However, the functional and clinical response of any specific PEP device may vary according to a specific diagnostic group. Ultimately, the choice of airway clearance strategy may be the one that is clinically effective, cost-effective and preferred by the patient and, therefore, supports adherence.

Recent technology has led to the creation of a new machine able to apply a TPEP at a level several times lower than that applied with previous devices, and thus is able, at least potentially, to reduce the risk of mechanical stress injury in the bronchial tree and lung parenchyma. However, preliminary data on the use of TPEP cannot allow any firm conclusions; future clinical research might enable new windows to be opened in the field of chest physiotherapy with this device.

References

1. Myers TN. Positive expiratory pressure and oscillatory positive expiratory pressure therapies. *Respir Care* 2007; 52: 1308–1327.
2. Bott J, Blumenthal S, Buxton M, *et al*. Guidelines for the physiotherapy management of the adult, medical, spontaneously breathing patient. *Thorax* 2009; 64: i1–i52.
3. Clini EM, Degli Antoni F, Vitacca M, *et al*. Intrapulmonary percussive ventilation in tracheostomized patients: a randomized controlled trial. *Intensive Care Med* 2006; 34: 1994–2001.

4. Branson RD. Secretion management in the mechanically ventilated patients. *Respir Care* 2007; 52: 1328–1347.
5. Pryor JA. Physiotherapy for airway clearance in adults. *Eur Respir J* 1999; 14: 1418–1424.
6. Oberwaldner B, Evans JC, Zach MS. Forced expirations against a variable resistance: a new chest physiotherapy method in cystic fibrosis. *Pediatr Pulmonol* 1986; 2: 358–367.
7. Groth S, Stafanger G, Dirksen H, Anderson JB, Falk M, Kelstrup M. Positive expiratory pressure (PEP-mask) physiotherapy improves ventilation and reduces volume of trapped gas in cystic fibrosis. *Bull Eur Physiopathol Respir* 1985; 21: 339–343.
8. App EM, Kieselmann R, Reinhardt D, *et al*. Sputum rheology changes in cystic fibrosis lung disease following two different types of physiotherapy: flutter *versus* autogenic drainage. *Chest* 1998; 114: 171–177.
9. Volsko TA, Di Fiore JM, Chatburn RL. Performance comparison of two oscillating positive expiratory ressure devices: acapella *versus* flutter. *Respir Care* 2003; 48: 124–130.
10. McIlwaine M. Physiotherapy and airway clearance techniques and devices. *Paediatr Respir Rev* 2006; 7: S220–S222.
11. Darbee JC, Ohtake PJ, Grant BJ, Cerny FJ. Physiologic evidence for the efficacy of positive expiratory pressure as an airway clearance technique in patients with cystic fibrosis. *Phys Ther* 2004; 84: 524–537.
12. Richter Larsen K, Ingwersen U, Thode S, Jakobsen S. Mask physiotherapy in patients after heart surgery: a controlled study. *Intensive Care Med* 1995; 21: 469–474.
13. Fagevik-Olsen M, Westerdahl E. Positive expiratory pressure in patients with chronic obstructive pulmonary disease. A systematic review. *Respiration* 2009; 77: 110–118.
14. Christensen EF, Nedergaard T, Dahl R. Long-term treatment of chronic bronchitis with positive expiratory pressure mask and chest physiotherapy. *Chest* 1990; 97: 645–650.
15 Thompson CS, Harrison S, Ashley J, Day K, Smith DL. Randomised crossover study of the Flutter device and the active cycle of breathing technique in non-cystic fibrosis bronchiectasis. *Thorax* 2002; 57: 446–448.
16. Newbold ME, Tullis E, Corey M, Ross B, Brooks D. The Flutter device *versus* the PEP mask in the treatment of adults with cystic fibrosis. *Physiother Can* 2005; 57: 199–207.
17. Hess DR. The evidence for secretion clearance techniques. *Respir Care* 2001; 46: 1276–1292.
18. Kendrick AH. Airway clearance techniques in cystic fibrosis: physiology, devices and the future. *J R Soc Med* 2007; 100: 3–23.
19. McCarren B, Alison JA. Physiological effects of vibration in patients with cystic fibrosis. *Eur Respir J* 2006; 27: 1204–1209.
20. Macklem PT. Airway obstruction and collateral ventilation. *Physiol Rev* 1971; 51: 368–436.
21. Cetti EJ, Moore AJ, Geddes DM. Collateral ventilation. *Thorax* 2006; 61: 371–373.
22. Higuchi T, Reed A, Oto T, *et al*. Relation of interlobar collaterals to radiological heterogeneity in severe emphysema. *Thorax* 2006; 61: 409–413.
23. Garrard CS, Shah M. The effects of expiratory positive airway pressure on functional residual capacity in normal subjects. *Crit Care Med* 1978; 6: 320–322.
24. Hyatt RE, Wilson TA. Forced expiration. *In:* Crystal RG, West JB, Weibel ER, Barnes PJ. (eds) The Lung. Philadelphia, Lippincott–Raven, 1997; p 1400.
25. Medical Products Research. www.mpr-italy.it Date last accessed: September 25, 2009.
26. Fazzi P, Girolami G, Albertelli R, Grana M, Mosca F, Giuntini C. IPPB with temporary expiratory pressure (TPEP) in surgical patients with COPD. *Eur Respir J* 2008; 32, Suppl. 52, 577s.
27. Clinical efficacy of temporary expiratory pressure (TPEP) device in chronic hypersecretion – Clinical Trials No NCT00700388. www.clinicaltrial.gov/ct2/show/NCT00700388?cond=%22Bronchiectasis%22&rank=27 Date last accessed: October 7, 2009.

Educational questions

True or False

1. The use of PEP devices to clear secretion is the only modality for treating patients nowadays.
2. PEP devices have similar effects in patients with different underlying conditions.
3. The Flutter device must be pointed upward for maximum efficacy.
4. From an evidence-based perspective, PEP and OPEP provide similar efficacy in patients with hypersecretion.
5. Patients suffering from CF are more likely to be treated with PEP devices.
6. TPEP delivers expiratory pressure to the airways which is several times lower than that provided with different PEP techniques.

Suggested answers

1. False
2. False
3. True
4. True
5. True
6. True