

Physiological Responses to Positive Expiratory Pressure Breathing: A Comparison of the PEP Bottle and the PEP Mask

Maria Sehlin RPT MSc, Fredrik Öhberg, Göran Johansson MSc, and Ola Winsö MD PhD

BACKGROUND: In the intensive care unit we have observed that patients have different adherence to 2 commonly used positive-expiratory-pressure (PEP) therapy devices: the PEP bottle and the PEP mask. The reason for this difference is not clear. **METHODS:** In a randomized prospective study, we made continuous recordings of airway pressure and airflow, with 20 healthy volunteers, with the PEP bottle and the PEP mask. The measurement sequence consisted of 3 sessions of 10 breaths with the PEP bottle and the PEP mask, in a randomized crossover design. A rest period of 15 min separated the PEP bottle and PEP mask measurements. **RESULTS:** With the PEP bottle the expiratory phase began with a zero-flow period of 0.39 s, during which airway pressure rose 11.9 cm H₂O. With the PEP bottle the mean expiratory pressure was 11.7 cm H₂O, and end-expiratory pressure was 9.5 cm H₂O. With the PEP mask the initial expiratory zero-flow period was almost nonexistent (0.04 s) and without any change in airway pressure. With the PEP mask the shape of the expiratory pressure curve was different; mean expiratory pressure was 8.6 cm H₂O, and end-expiratory pressure was zero. With the PEP bottle the inspiration also began with a zero-flow period of 0.43 s, during which airway pressure decreased 9.6 cm H₂O from the end-expiratory airway pressure. With the PEP mask the initial inspiratory zero-flow period was only 0.01 s and there was no concomitant change in airway pressure. **CONCLUSIONS:** The PEP bottle and the PEP mask showed major differences in the relationship between airflow and airway pressure. These findings might explain the observed differences in patient adherence to these therapies. *Key words:* positive expiratory pressure, PEP, airflow, airway pressure, Borg scale, chest physiotherapy, flow resistor, threshold resistor. [Respir Care 2007;52(8):1000–1005. © 2007 Daedalus Enterprises]

Introduction

For a long time, chest physiotherapy has been an established form of treatment for pulmonary complications af-

ter abdominal and cardiac surgery.¹ Chest physiotherapy after abdominal surgery reduced the frequency of pulmonary complications, compared to an untreated control group.^{2,3} Although research has been done in this field since the 1950s, there is still controversy over which chest physiotherapy method is most effective.^{1,4–7} Recent studies confirm the importance of chest physiotherapy after cardiac surgery.^{8,9}

Positive expiratory pressure (PEP) breathing is a form of chest physiotherapy in which the patient expires against a resistance. There are 2 conceptually different methods to apply PEP: threshold resistor devices, and flow resistor devices.^{10,11} The PEP mask (a flow resistor device) was

Maria Sehlin RPT MSc is affiliated with the Department of Community Medicine and Rehabilitation, Physiotherapy; Fredrik Öhberg is affiliated with the Department of Radiation Sciences; and Göran Johansson MSc and Ola Winsö MD PhD are affiliated with the Department of Surgical and Perioperative Sciences, Anesthesiology and Intensive Care Medicine, Umeå University, Umeå, Sweden.

This research was supported by grants from the Swedish Association of Registered Physiotherapists. The authors report no other conflicts of interest.

Maria Sehlin RPT MSc presented a version of this paper at the meeting of the Scandinavian Society of Anaesthesiology and Intensive Care Medicine, held July 2, 2005, in Reykjavik, Iceland, and at the Swedish Association of Registered Physiotherapists Congress, held October 28, 2005, in Stockholm, Sweden.

Correspondence: Maria Sehlin RPT MSc, Department of Community Medicine and Rehabilitation, Physiotherapy, Operationscentrum, Umeå University Hospital, S-901 85 Umeå, Sweden. E-mail: maria.sehlin@vll.se.

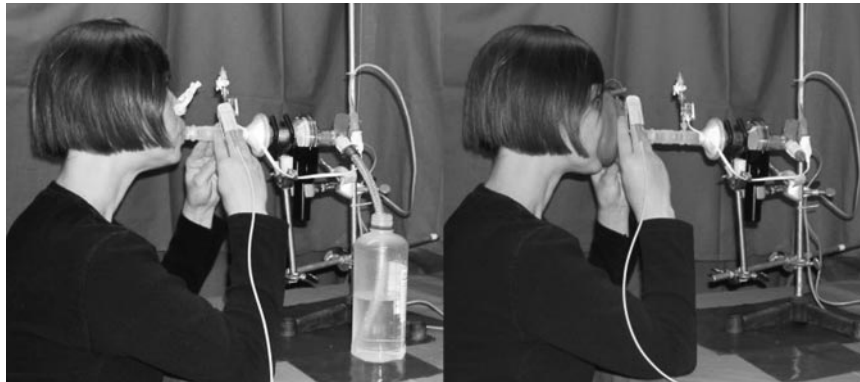


Fig. 1. Left: Positive expiratory pressure (PEP) bottle setup. Right: PEP mask setup.

developed in Denmark in the late 1970s, and it soon became a popular treatment in Scandinavia, Europe, and Canada.^{12,13} With the PEP mask, the magnitude of the expiratory pressure is determined by airflow and by the applied outflow resistor. The PEP mask is thus a flow resistor device. At a constant expiratory flow, the outflow resistance is inversely correlated to the diameter of the outflow resistor. PEP is also related to airflow. With a given outflow resistor, an increase in flow increases PEP, and a decrease in flow decreases PEP.

During the last decade, most departments of infectious disease in Sweden have introduced the PEP bottle (a threshold resistor device), which is now a common treatment for uncomplicated pneumonia.¹⁴ With the PEP bottle, the expiratory resistance consists of a water seal. To obtain airflow through the PEP bottle, the patient has to establish an airway pressure higher than the water seal before expiration occurs. With the PEP mask, airflow starts immediately at the beginning of the expiration.

In our daily practice in the intensive care unit we observed that some patients are not able to exhale more than a few times through the PEP bottle before they have to rest. After some normal breaths they are able to continue their PEP bottle exhalations. Their capacity to exhale through the PEP bottle is not improved by reducing the amount of water in the water seal. Our experience has been that the PEP mask suits our patients better than the PEP bottle. With the PEP mask they are able to do 10–15 consecutive exhalations at a PEP of 10 cm H₂O without becoming dyspneic. The reason for this difference is not clear. Some theories exist concerning physiological responses to PEP breathing,^{15,16} but there have been few direct comparisons of the PEP bottle and PEP mask. The PEP bottle used today is less evaluated than the PEP mask, and results with the PEP mask are often applied also with the PEP bottle.

With healthy volunteers we measured the airway pressure and expiratory airflow with the PEP bottle and the PEP mask, to objectively evaluate the devices. We also

collected the volunteers' estimations of their perceived exertion, using the Borg category ratio (CR) 10 scale, as a subjective evaluation.¹⁷

Methods

The study was approved by the research ethics committee of the medical faculty of Umeå University, and informed consent was obtained from each participant. Twenty healthy volunteers (mean \pm SD age 37 ± 9 y, 13 women, 7 men) participated. Prior to PEP measurements, we measured (Model 5, Vitalograph, Buckingham, United Kingdom) vital capacity and forced expiratory volume in the first second (FEV₁) in all 20 participants. A physiotherapist who was experienced in pulmonary function measurements performed the tests. The participants were seated, and a nose-clip was used. The best of 3 maneuvers within 10 min was used for both vital capacity and FEV₁.

Figure 1 shows the PEP measurement setups. In all the measurements the participants breathed through a pressure transducer, followed by a bacterial filter and an airflow transducer. A T-valve that separated the inspiratory and expiratory airflow was connected to the distal end of the airflow transducer.

The PEP bottle device consisted of a bottle with 10 cm of water and a 42-cm plastic tube (inner diameter 1 cm) connected to the expiratory limb of the T-valve. The end of the tube was 10 cm below the water surface, which provided an expiratory pressure of approximately 10 cm H₂O. A nose-clip and a mouthpiece were used when breathing through the PEP bottle.

The PEP mask consists of a face mask, to which various resistors (inner diameter range 1.5–5.0 mm) can be connected. The chosen resistor was connected to the expiratory limb of the T-valve.

The participants sat on an adjustable chair in front of the table, with 90-degree flexion of the knees and hips, and with the feet firmly on the floor or, if needed, a footstool. The subject's elbows were placed on the table, and the

subject's fingers were placed on the mask or mouthpiece (see Fig. 1). All participants practiced with both the PEP bottle and the PEP mask before the measurements began. They were instructed to breathe in and out through the mouth, to take a deep breath and exhale slightly actively, and to try to find a rhythm they felt comfortable with. When practicing with the PEP mask, expiratory pressure was measured with a manometer connected to the expiratory valve. The resistor chosen for each participant was the resistor that resulted in an expiratory pressure of approximately 10 cm H₂O. The inner diameter of the resistors used ranged from 2.0 mm to 4.5 mm.

When the participant felt comfortable using the 2 PEP devices, a 15-min pause took place before the PEP measurements began. During the 15-min pause the participants were instructed how to use the Borg CR 10 scale,¹⁷ and electrocardiogram measurements were started. The electrocardiography continued during the whole test procedure.

During PEP breathing, airway pressure, airflow, and blood oxygen saturation (measured via pulse oximetry) were recorded continuously at 200 Hz, with waveform acquisition and analysis software.

The measurement sequence consisted of 3 sessions of 10 breaths with either the PEP mask or the PEP bottle, in a random order (sealed envelopes). A 2-min pause separated each session of 10 breaths. To avoid carryover effects, the subject had a rest period of 15 min before measurements with the second PEP device. After the third session with each PEP device, the participants estimated their perceived exertion, with the Borg CR 10 scale.¹⁷

Calibrations

Before the tests, the pressure transducer was calibrated with a water column. A 2-point calibration procedure was used (ie, the transducer was calibrated with 0 cm of water and with a 10 cm water column). In addition, the pressure transducer was tested during a longer period to evaluate offset drift and sensitivity drift. The sensitivity drift was small, compared to the offset drift. The offset drift was therefore compensated for before each test series.

The airflow transducer was calibrated with a 600-mL calibration syringe before every third session of 10 breaths. However, because of unknown artifacts, the airflow signal was initially impossible to calibrate to 0 L/s. There was constant drift in the airflow baseline, which persisted throughout the registration period. This drift had to be dealt with in 2 steps, in accordance with instructions from the manufacturer and from local research engineers. Airflow baseline drift, as measured during a period with no airflow, was subtracted from the registered airflow signal. Any existing trend in the airflow signal was then removed.

The airway pressure signal was adjusted similarly. Thus, mean airway pressure during zero airflow was measured and then subtracted from the airway pressure signal.

Analyses of the airway pressure and airflow recordings were done manually for each individual breath. The shift between inspiration and expiration was defined as the point when the airflow signal passed zero L/s; that is, when the airflow signal changed from a positive (inspiration) to a negative (expiration) value, or vice versa.

Statistical Analysis

We used the paired *t* test to compare the PEP mask and PEP bottle data. A *p* value < 0.05 was considered statistically significant. Data are presented as mean ± SD, except for the Borg scores, which are reported as median and range values. Statistical analyses were performed with statistics software (SPSS for Windows 12.0, SPSS, Chicago, Illinois).

Results

Demographic Data

Our 20 healthy volunteers had normal baseline pulmonary function: mean ± SD vital capacity 4.33 ± 0.92 L (80–131% of predicted) and FEV₁ 3.57 ± 0.76 L (83–127% of predicted). All the participants were nonsmokers. There were no significant differences in heart rate over time, within or between the PEP mask and PEP bottle “groups.” Oxygen saturation was 97–99%.

Changes in Airway Pressure

With the PEP bottle, after a deep inspiration, the expiratory phase began with a 0.39 s zero-flow period, during which airway pressure rose 11.9 cm H₂O but no airflow occurred. With the PEP mask, the expiratory zero-flow period was only 0.04 s and the change in airway pressure was 0.4 cm H₂O (Fig. 2).

Figure 3 shows the mean and maximum expiratory pressures, the ratios of mean to maximum airway pressure, and the end-expiratory airway pressures. Both the maximum (14.9 cm H₂O) and mean (11.7 cm H₂O) expiratory pressures were higher with the PEP bottle. The ratio of mean to maximum airway pressure was slightly higher with the PEP bottle than with the PEP mask (see Fig. 3C).

At the end of the expiration, airway pressure was much higher with the PEP bottle (9.5 cm H₂O) than with the PEP mask (near zero) (see Fig. 3D).

With the PEP bottle the inspiration started after a zero-flow period of 0.43 s, during which airway pressure decreased 9.6 cm H₂O from the end-expiratory airway pressure level. With the PEP mask the inspiratory zero-flow

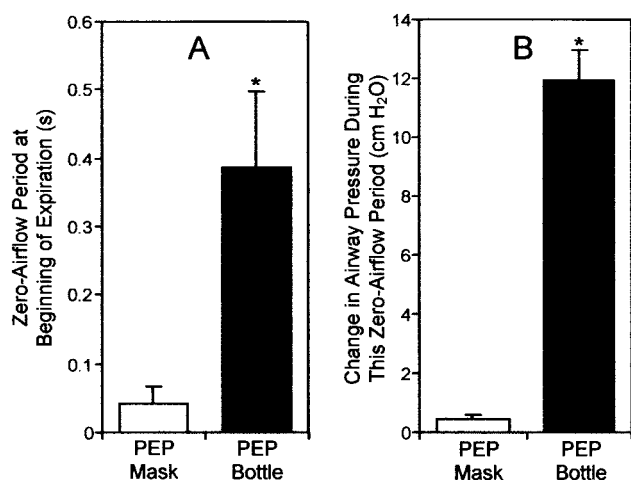


Fig. 2. A: Zero-airflow period at the beginning of expiration. B: Change in airway pressure during this zero-airflow period. The values are mean \pm SD. * $p < 0.001$.

period was 0.01 s, and there was no change in airway pressure from the end-expiratory airway pressure level (Fig. 4).

Changes in Airflow

Figure 5 shows the maximum and mean expiratory airflows, both of which were higher with the PEP bottle than with the PEP mask.

Breathing Pattern

The mean inspiratory time was 2.56 ± 0.83 s with the PEP bottle and 2.25 ± 0.74 s with the PEP mask ($p < 0.001$). Mean expiratory time was 5.14 ± 1.54 s with the PEP bottle and 5.80 ± 2.0 s with the PEP mask ($p = 0.068$).

Peak airway pressure and peak airflow occurred within the first 60% of the expiratory phase with the PEP bottle, and within the first 50% of the expiratory phase with the PEP mask.

The mean inspiratory-expiratory ratio was 0.52 ± 0.14 (ie, 1:2) with the PEP bottle and 0.41 ± 0.12 (1:2.5) with the PEP mask ($p = 0.005$). The time required for 10 consecutive breaths was similar with the PEP bottle and the PEP mask: 77 ± 22 s versus 80 ± 25 s, respectively ($p = 0.29$).

Perceived Exertion

The participants' perceived exertion was measured with the Borg CR 10 scale.¹⁷ The median perceived exertion was 2.5 (range 0–5) with the PEP mask, and 2 (range 0–5) with the PEP bottle. Twelve participants rated their perceived exertion higher with the PEP mask, and 5 partici-

pants rated their perceived exertion higher with the PEP bottle. The remaining 3 participants felt that there were no difference in their perceived exertion between the 2 PEP devices.

Discussion

The PEP bottle is, by tradition, the first choice among PEP devices at our university hospital, and it is used daily. However, some patients are not able to take more than a few breaths with the PEP bottle, whereas they are able to take 10–15 consecutive breaths with the PEP mask. This difference in patient compliance has not been previously investigated. We therefore chose to compare the PEP bottle with the PEP mask. These PEP devices represent 2 different principles for applying PEP. Breathing with the PEP bottle (a threshold resistor device) is done with a mouthpiece, and the exhalation is through a water seal, whereas the PEP mask (a flow resistor device) is done with a face mask equipped with an expiratory resistor.

We found major differences in the relationship between airflow and airway pressure with the PEP mask and PEP bottle during both expiration and inspiration. With the PEP bottle the expiratory phase began with a zero-flow period, during which airway pressure rose rapidly. With the PEP mask the expiratory zero-flow period was almost nonexistent, and without change in airway pressure. The duration of the zero-flow period with the PEP bottle reflects the time required for the airway pressure to rise above the water seal level. When the airway pressure reaches that level, airflow begins. At the end of the expiration, airway pressure was 9.5 cm H₂O with the PEP bottle and zero with the PEP mask.

With the PEP bottle the inspiration began with a zero-flow period, which was an interesting and unexpected observation. During this zero-flow period, airway pressure decreased from the end-expiratory airway pressure level to slightly below zero. With the PEP mask the inspiratory zero-flow period was much shorter and there was no change in airway pressure during that very brief zero-flow period.

The zero-flow periods make the patient briefly hold his or her breath, and it is therefore possible that the longer zero-flow periods (during both expiration and inspiration) cause some patients to become dyspneic with the PEP bottle.

Some methodological considerations have to be addressed. Outflow resistance of different positive expiratory pressure systems has previously been tested in vitro, with various ventilator systems and constant-airflow devices (rotameters),^{11,18–21} whereas in vivo data are sparse. Many threshold resistors show flow dependence when airflow increases.¹¹ With the water seal, when the airflow is above 30 L/min, airway pressure increases.²² Christensen et al¹⁹ compared 3 flow resistors (PEP mask, Pari-PEP, and System 22-PEP) with 3 threshold resistors (underwater seal, Vital Signs PEEP

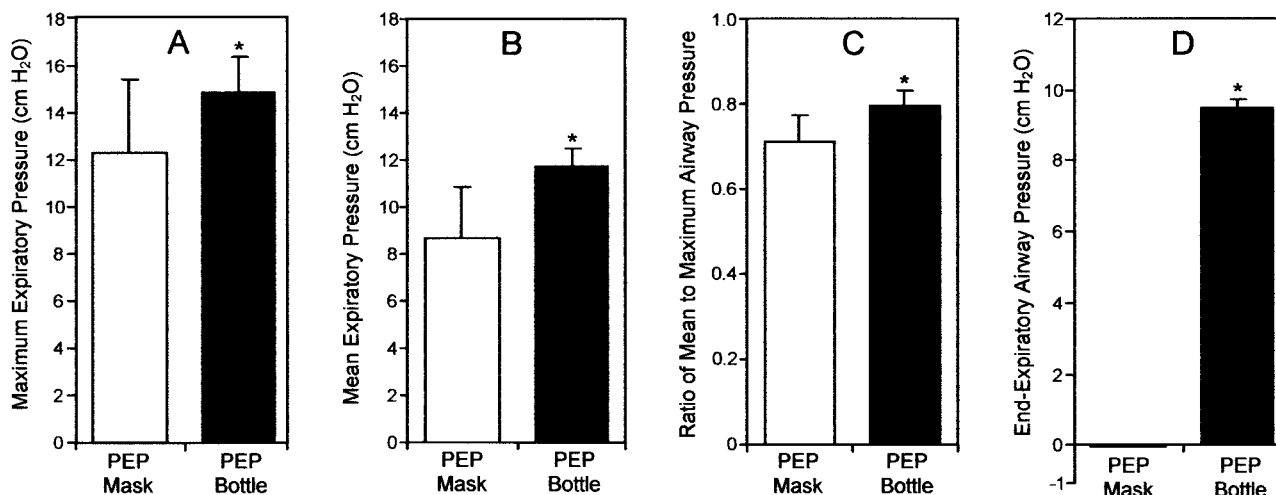


Fig. 3. A: Maximum expiratory airway pressure. B: Mean expiratory airway pressure. C: Ratio of mean to maximum airway pressure. D: End-expiratory airway pressure. The values are mean ± SD. * $p < 0.001$.

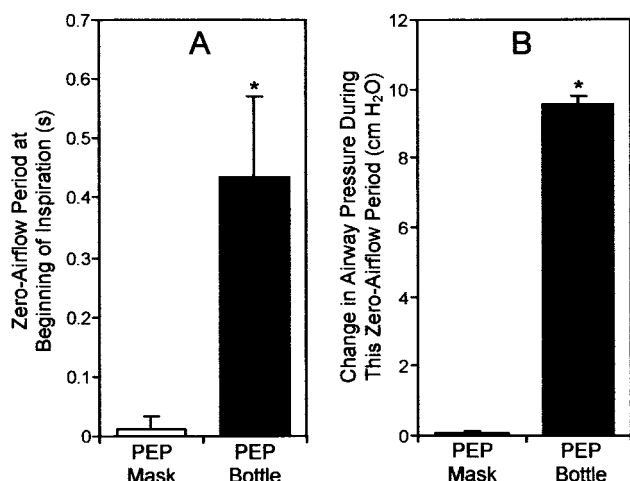


Fig. 4. A: Zero-airflow period at the beginning of inspiration. B: Change in airway pressure during this zero-airflow period. The values are mean ± SD. * $p < 0.001$.

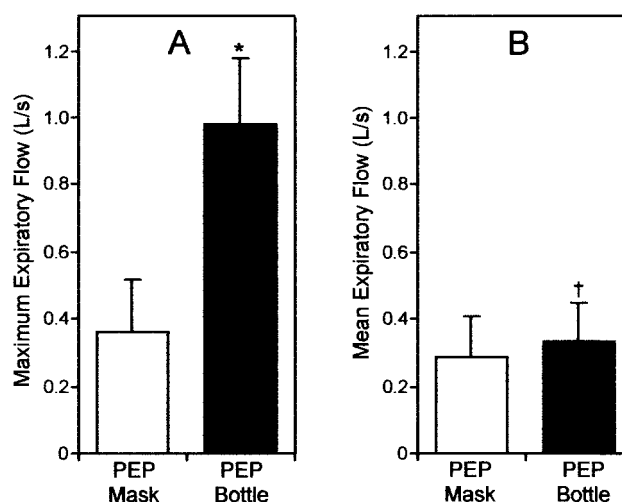


Fig. 5. A: Maximum expiratory airflow. B: Mean expiratory airflow. The values are mean ± SD. * $p < 0.001$. † $p < 0.026$.

valve, and Ambu PEEP valve) and concluded that the water seal is an almost ideal threshold resistor. They also found a minor degree of flow dependence, especially at higher pressures, and that a T-valve itself could act as a resistor.

Limitations of the present study include the fact that the subjects used a mask when breathing through the PEP mask and a mouthpiece when breathing through the PEP bottle. We chose these methods because they resemble standard clinical use. Further, there are some minor differences in compressible gas volume between the different PEP devices (10.5 mL), which might influence the results, but probably only to a minor degree.

In the present study our intention was that the participants breathe against an expiratory pressure of 10 cm H₂O, with both PEP devices. However, both maximum and mean

expiratory airway pressure differed significantly between the PEP bottle and the PEP mask. The mean expiratory airflow with the PEP bottle was 0.33 L/s, and a T-valve was used for separating the inspiratory airflow from the expiratory airflow. Both the use of the T-valve and the velocity of the expiratory airflow could explain why the measured mean expiratory airway pressure was higher than 10 cm H₂O with the PEP bottle.

We observed lower airway pressures than expected with the PEP mask. This might be due to the fact that some participants changed their way of breathing, compared to the initial instruction phase. To avoid external disturbances, such alterations in breathing pattern were not addressed with further instructions to the participant.

The mean expiratory airflow we observed (0.29 L/s with the PEP mask and 0.33 L/s with the PEP bottle) is in line

with earlier findings. Control-group data (healthy persons) from previous studies, which included tetraplegic patients²³ and obese patients,²⁴ consistently showed mean expiratory airflow of 0.3 L/s with the PEP mask in the healthy persons. However, maximum expiratory airflow was much higher with the PEP bottle than with the PEP mask in the present study. Data on maximum expiratory flow might, however, be questioned, so airflow was measured with an airflow transducer that is adequate for measuring airflow of ≤ 5 L/s. If airflow is turbulent, falsely high airflow values might be reported.²⁵ It is possible that the oscillating airflow that occurs with the PEP bottle resulted in falsely high maximum expiratory flow values.

Airway pressure and airflow are objective measures, but the Borg CR 10 scale¹⁷ provides only a subjective measurement of perceived exertion. Data on perceived exertion are not easy to deduce. Interestingly, there were great differences in the perceived exertion among the participants. Some participants reported their perceived exertion at 5 (on a 1–10 scale), whereas others reported no perceived exertion. Considering the wide range in these data from healthy volunteers, one can easily understand that patients have different capacities to breathe through different PEP devices.

Conclusions

There were major differences between the PEP bottle and the PEP mask in the relationship between airflow and airway pressure, during both expiration and inspiration. With the PEP bottle, both expiration and inspiration began with a zero-flow period, during which airway pressure changed rapidly. There was no such pressure change during the very short zero-flow period with the PEP mask. The duration of the zero-flow periods may explain why some patients lose their breath when using the PEP bottle and do not when using the PEP mask. These findings from healthy volunteers might reflect the observed differences in patient adherence to PEP therapy, which merits further investigation. It would be of special interest to study post-operative patients and intensive care unit patients with chronic obstructive pulmonary disease.

REFERENCES

1. Bourn J, Jenkins S. Post-operative respiratory physiotherapy indications for treatment. *Physiotherapy* 1992;78(2):80–85.
2. Thoren L. Post-operative pulmonary complications: observations on their prevention by means of physiotherapy. *Acta Chir Scand* 1954; 107(2–3):193–205.
3. Fagevik Olsén M, Hahn I, Nordgren S, Lönroth H, Lundholm K. Randomized controlled trial of prophylactic chest physiotherapy in major abdominal surgery. *Br J Surg* 1997;84(9):1535–1538.
4. Ingwersen UM, Larsen KR, Bertelsen MT, Kiil-Nielsen K, Laub M, Sandermann J, et al. Three different mask physiotherapy regimens

- for prevention of post-operative pulmonary complications after heart and pulmonary surgery. *Intensive Care Med* 1993;19(5):294–298.
5. Richter Larsen K, Ingwersen U, Thode S, Jakobsen S. Mask physiotherapy in patients after heart surgery: a controlled study. *Intensive Care Med* 1995;21(6):469–474.
6. Olsén MF. Chest physiotherapy in open and laparoscopic abdominal surgery. *Phys Ther Rev* 2000;5(2):125–130.
7. Westerdahl E, Lindmark B, Almgren SO, Tenling A. Chest physiotherapy after coronary artery bypass graft surgery: a comparison of three different deep breathing techniques. *J Rehabil Med* 2001;33(2): 79–84.
8. Westerdahl E, Lindmark B, Eriksson T, Hedenstierna G, Tenling A. The immediate effect of deep breathing exercises on atelectasis and oxygenation after cardiac surgery. *Scand Cardiovasc J* 2003;37(6): 363–367.
9. Westerdahl E, Lindmark B, Eriksson T, Friberg Ö, Hedenstierna G, Tenling A. Deep-breathing exercises reduce atelectasis and improve pulmonary function after coronary artery bypass surgery. *Chest* 2005; 128(5):3482–3488.
10. Kacmarek RM, Dimas S, Reynolds J, Shapiro BA. Technical aspects of positive end-expiratory pressure (PEEP): Part I. Physics of PEEP devices. *Respir Care* 1982;27(12):1478–1489.
11. Banner MJ, Lampotang S, Boysen PG, Hurd TE, Desautels DA. Flow resistance of expiratory positive-pressure valve systems. *Chest* 1986;90(2):212–217.
12. Campbell T, Ferguson N, McKinlay RGC. The use of a simple-administered method of positive expiratory pressure (PEP) in chest physiotherapy after abdominal surgery. *Physiotherapy* 1986;72(10): 498–500.
13. Mahlmeister MJ, Fink JB, Hoffman GL, Fifer LF. Positive-expiratory-pressure mask therapy: theoretical and practical considerations and a review of the literature. *Respir Care* 1991;36(11):1218–1230.
14. Björkqvist M, Wiberg B, Bodin L, Barany M, Holmberg H. Bottle-blowing in hospital-treated patients with community-acquired pneumonia. *Scand J Infect Dis* 1997;29(1):77–82.
15. Ingwersen I, Andersen JB. *Rationel lungefysioterapi*, 3rd ed. Copenhagen: Munksgaard; 1987: 75–76.
16. Hough A. *Physiotherapy in respiratory care: a problem-solving approach to respiratory and cardiac management*, 2nd ed. London: Chapman & Hall; 1996: 136–137.
17. Borg G. Borg's perceived exertion and pain scales. *Campaign, Ill: Human Kinetics*; 1998: 39–52.
18. Pinsky MR, Hrehocik D, Culpepper JA, Snyder JV. Flow resistance of expiratory positive-pressure systems. *Chest* 1988;94(4):788–791.
19. Christensen EF, Jensen RH, Schonemann NK, Petersen KD. Flow-dependent properties of positive expiratory pressure devices. *Monaldi Arch Chest Dis* 1995;50(2):150–153.
20. Brooks D, Newbold E, Kozar LF, Rivera M. The flutter device and expiratory pressures. *J Cardiopulm Rehabil* 2002;22(1):53–57.
21. 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.
22. Hall JR, Rendleman DC, Downs JB. PEEP devices: flow-dependent increases in airway pressure (abstract). *Crit Care Med* 1978;6:100.
23. Bodin P, Kreuter M, Bake B, Olsén MF. Breathing patterns during breathing exercises in persons with tetraplegia. *Spinal Cord* 2003; 41(5):290–295.
24. Olsén MF, Lönroth H, Bake B. Effects of breathing exercises on breathing patterns in obese and non-obese subjects. *Clin Physiol* 1999;19(3):251–257.
25. Sullivan WJ, Peters GM, Enright PL. Pneumotachographs: theory and clinical application. *Respir Care* 1984;29(7):736–748.