An Improvised “Blow Glove” Device Produces Similar PEP Values to a Commercial PEP Device: An Experimental Study

Yaakov Dagan, PT, MSc;* Itay Wiser, MD, PhD;‡ Oren Weissman, MD;§
Nimrod Farber, MD;§ Gabriel Hundeshagen, BMedSc;§ Eyal Winkler, MD;§
Tamar Kazula-Halabi, RN, RT, MPH;† Josef Haik, MD, MPH§

ABSTRACT

Background: Postoperative positive expiratory pressure (PEP) therapy promotes increased lung volume, secretion clearance, and improved oxygenation. Several commercial devices exist that produce recommended PEP values (10–20 cmH₂O) when the patient breathes through a fixed orifice resistor. It was hypothesized that an inexpensive, improvised “blow glove” device would produce similar PEP values over a wider range of expiration volumes and flow rates. **Methods:** PEP for different expiration volumes (400–2000 mL) and expiratory flow rates (10–80 L/min) was compared between a commercial PEP device (Resistex, Mercury Medical, Clearwater, FL) and an improvised “blow glove” device, recorded by a Vela ventilator (CareFusion, San Diego, CA). Dynamics in positive end expiratory pressure (PEEP) values were evaluated following five consecutive expirations. The “blow glove” device was evaluated using various glove compositions and sizes. **Results:** The improvised “blow glove” device produced a significantly higher rate of PEP values in the recommended range than the Resistex device (88.9% vs. 20%, $p < 0.0001$). No significant difference was observed between small and large glove sizes (88.9% vs. 82.9%, $p > 0.05$), 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%, $p < 0.001$). **Conclusions:** A “blow glove” PEP device using a powdered latex glove produces PEP values in the recommended range over a wider spectrum of expiratory flow rates and expiration volumes than a commercial PEP device.

Key Words: breathing exercises; positive-pressure end expiration pressure; pulmonary atelectasis.

RÉSUMÉ

Contexte : La thérapie postopératoire à pression expiratoire positive (PEP) favorise l'augmentation du volume des poumons, le dégagement des sécrétions et une meilleure oxygénation. Plusieurs appareils commerciaux sur le marché produisent les valeurs de PEP recommandées (de 10 à 20 cmH₂O) lorsqu'on souffle dans un dispositif de résistance à ouverture fixe. On a fait l'hypothèse qu'un appareil bon marché et improvisé à partir d'un « gant dans lequel on souffle » produirait des valeurs de PEP semblables dans une plus vaste plage de volumes d'expiration et de débits. **Méthodes :** La PEP pour différents volumes d'expiration (de 400 à 2 000 mL) et débits expiratoires (10–80 L/min) a été comparée en utilisant un appareil commercial de PEP (Resistex, Mercury Medical, Clearwater, Floride) et un appareil improvisé à partir d'un gant, puis enregistrée par un respirateur Vela (CareFusion, San Diego, Californie). La dynamique des valeurs de la pression positive en fin d'expiration (PPFE) a été évaluée après cinq expirations consécutives. L'évaluation de l'appareil fabriqué à l'aide d'un gant a été effectuée en utilisant des gants de compositions et de tailles diverses. **Résultats :** L'appareil improvisé à partir d'un gant a produit un taux considérablement plus élevé de valeurs de PEP dans la plage recommandée que l'appareil Resistex (88,9% c. 20%, $p < 0,0001$). Aucune différence importante n'a été observée entre les petites et les grandes tailles de gants (88,9% c. 82,9%, $p > 0,05$). Le gant en latex poudré affichait un taux considérablement plus élevé de valeurs de PEP dans la plage recommandée que le gant en latex non poudré (88,9% c. 44,4%, $p < 0,001$). **Conclusions :** Un appareil de PEP improvisé à l'aide d'un gant en latex poudré produit de plus grandes plages de PEP recommandée par spectre de débit d'expiration comparativement à un appareil commercial de PEP.

Pulmonary complications are commonly observed in the early postoperative period following cardiac, thoracic, and abdominal surgeries.^{1–5} These complications are

usually associated with increased hospital length of stay (LOS) as well as higher mortality rates.⁶ A variety of chest physical therapy techniques have long been a standard

From the: *Physiotherapy Service and †Respiratory Equipment Service, Sheba Medical Center, Tel Hashomer, Israel; ‡Department of Plastic Surgery, Assaf Harofeh Medical Center, Zerifin (affiliated to Sackler Faculty of Medicine, Tel Aviv University); §Department of Plastic and Reconstructive Surgery, Sheba Medical Center (affiliated to Sackler Faculty of Medicine, Tel Aviv University).

Yaakov Dagan and Itay Wiser contributed equally to this study.

Correspondence to: Oren Weissman, The Department of Plastic and Reconstructive Surgery, Sheba Medical Center, Ramat Gan, Israel orenweissman@gmail.com.

Contributors: All authors designed the study; collected, analyzed, and interpreted the data; drafted or critically revised the article; and approved the final draft.

Competing Interests: None declared.

Physiotherapy Canada 2014; 66(3);308–312; doi:10.3138/ptc.2013-31

component of postoperative care, aiming to prevent or reduce the incidence of complications such as impaired pulmonary function, atelectasis, decreased oxygenation, sputum retention, and pneumonia.^{2,3,7–9}

One of the therapeutic principles of chest physical therapy is to create a positive expiratory pressure (PEP), which in turn increases pulmonary expiration time and pulmonary volumes, especially functional residual capacity.^{2,10} PEP levels between 10 and 20 cmH₂O are believed to improve mucus clearance, either by increasing gas pressure behind secretions through collateral ventilation or by preventing airway collapse during expiration.

There are many simple systems for creating PEP breathing postoperatively, including a PEP mask or mouthpiece incorporating variably sized resistors, a “blow-bottle” device in which the resistance consists of a water seal, and a “blow glove” device consisting of a latex medical examination glove attached to a long plastic tube.^{11,12} When a PEP mask or mouthpiece is used, the diameter of the orifice resistor is determined using a manometer for each patient to give a steady PEP of 10–20 cmH₂O during the middle part of expiration.¹³ The pressure achieved depends on the performance of the manoeuvre, the adjustable expiratory resistance, and the patient’s active expiratory flow.^{2,10}

The objective of our study was to document the PEP levels produced with the “blow glove” device for different values of respiratory parameters and to compare the results with PEP levels produced by an existing commercial PEP device. We also assessed the effect of different expiratory flows, different expiratory volumes, and the different glove sizes and compositions used on the PEP levels produced. Finally, we determined the effect of repeated glove inflations over time.

METHODS

Procedure

We evaluated two PEP devices. The first was the Resistex PEP device (Mercury Medical, Clearwater, FL), an expiratory resistance exerciser with a mouthpiece, 22mm adapter, and four different resistance settings (levels 1–4). The physical therapist chooses the appropriate setting to allow the patient to produce 10–20 cmH₂O expiratory pressure during the middle of an active, but not forced, exhalation.

The second PEP device we evaluated was a “blow glove” device assembled from a latex examination glove (PrimaSänger, Schrozberg, Germany) connected to an 8 mm tracheal tube using medical tape (see Figure 1). Two different sizes (small and large) of both powdered and powder-free gloves, for a total of four combinations, were used to create different versions of this device.

The study was conducted at the biomedical engineering laboratory of Sheba Medical Center in Tel Aviv, Israel. Each device was connected to a Vela ventilator (CareFu-

Figure 1 The “blow glove” device consists of a latex examination glove connected to an 8 mm tracheal tube by medical tape.

sion, San Diego, CA) to document PEP levels (cmH₂O) for incrementally increasing expiratory flow levels between 10 and 80 L/min and incrementing expiration volumes between 400 and 2000 mL.

For the “blow glove” device, we documented PEP and PEEP levels for each combination of expiratory flow and volume after five consecutive expirations. PEP was measured over 100 repetitions in each condition to assess changes in PEP due to decrement of the glove’s elastic characteristics. The desired PEP range was considered to be from 10 to 20 cmH₂O;¹⁴ any PEP level <10 cmH₂O or >20 cmH₂O was marked “out of range.” For the purpose of evaluating maximal expiratory flow range and physiologic expiratory flow range, we compared in-range and out-of-range PEP levels for both 10–80 L/min (maximal) and 10–40 L/min (physiologic) expiratory flow measurements.

Data analysis

Statistical analysis was performed using SPSS version 13 (SPSS Inc., Chicago, IL). Continuous variables were compared across the different PEP devices using paired *t*-tests; the Wilcoxon rank test was used for non-parametric variables. Differences in categorical variables were compared using chi-square tests. The threshold for statistical significance was set at *p* < 0.05.

RESULTS

Table 1 shows PEP levels stratified by device, expiratory flow, and expiratory volume. In-range PEP levels and percentages, compared by PEP device and calculated for maximal and physiologic expiratory flow, are shown in Table 2.

The percentage of in-range PEP levels for maximal expiratory flow range (10–80 L/min) using the “blow glove” device, using both small and large powdered latex gloves, was significantly higher than the percentage of in-range

Table 1 Positive Expiratory Pressure Levels (cmH₂O) Stratified by Expiratory Volume (mL), Expiratory Flow (L/min), and Device Used*

Device	Expiratory flow (L/min)	400 mL	600 mL	800 mL	1000 mL	1200 mL	1400 mL	1600 mL	1800 mL	2000 mL
Resistex										
Level 1	10	10	8	8	9	9	9	9	10	12
	20	20	21	19	21	21	21	22	22	23
	40	34	35	33	33	34	35	35	36	36
	60	42	42	43	44	45	45	46	47	47
	80	48	50	50	52	52	53	53	54	55
Level 2	10	5	5	5	5	5	6	6	7	8
	20	15	14	14	15	15	16	17	19	21
	40	28	30	29	31	31	33	34	35	36
	60	38	38	39	40	41	42	43	44	44
	80	46	46	47	48	48	49	50	51	52
Level 3	10	4	3	3	3	4	4	5	6	7
	20	11	11	11	11	12	12	13	14	14
	40	25	26	26	27	27	28	29	30	32
	60	34	36	36	39	40	42	43	45	46
	80	42	43	44	46	47	49	51	52	54
Level 4	10	2	1	1	1	2	2	3	3	4
	20	5	5	5	5	6	6	6	7	7
	40	15	16	16	17	17	19	20	21	22
	60	24	26	27	29	30	32	33	34	36
	80	32	34	35	36	37	39	40	42	44
“Blow glove”										
Powdered (L)	10	9	9	9	9	12	12	11	11	11
	20	9	10	9	9	12	12	12	11	12
	40	9	10	10	10	13	13	13	12	13
	60	11	12	11	12	15	16	15	16	16
	80	13	15	15	15	19	19	19	19	20
Powdered (S)	10	10	10	10	10	10	9	9	9	9
	20	10	10	10	10	10	10	10	11	9
	40	11	11	12	11	12	11	11	11	11
	60	12	13	14	13	14	14	14	14	14
	80	14	16	17	17	18	18	18	18	18
Powder-free (L)	10	18	21	21	20	20	18	17	17	16
	20	18	21	21	20	20	18	18	17	16
	40	19	22	22	21	20	19	18	18	17
	60	21	23	23	22	22	22	22	22	21
	80	23	25	26	27	27	27	27	27	27

*PEP values within the recommended range (10–20 cmH₂O) are shown in bold.

values for Resistex levels 1–4 (82.2% and 88.9% vs. 11.1%, 17.8%, 20.0%, and 15.6%, $p < 0.001$; see Table 2).

For physiologic expiratory flow range (10–40 L/min), the percentage of in-range PEP levels for the “blow glove” device (powdered latex, small and large sizes) was significantly higher than the percentage of in-range values for Resistex device levels 1–4 (70.4% and 81.5% vs. 18.5%, 29.6%, 33.3% and 25.9%, $p < 0.001$; see Figure 2).

The “blow glove” device using a powder-free latex glove (large size) produced a significantly higher percentage of in-range PEP levels in physiologic expiratory flow range than in maximal expiratory flow range (74.1% vs. 44.4%, $p = 0.03$). Results were similar for other sizes of powder-free gloves (data are not presented here).

We documented a mean decrement in PEP levels of 1.2 (SD 0.6) cmH₂O with the “blow glove” device (both small and large powdered latex gloves) after 50–100

exhalations. For the powder-free glove, the mean decrement was 1.5 (SD 0.8) cmH₂O after a similar number of inflations. No additional variability was observed following 100 consecutive exhalations ($p = 0.89$).

PEEP was recorded for the “blow glove” device using the different gloves after five consecutive exhalations. The glove was inflated to a maximum of 10 L. The mean PEEP level was 8 (SD 1.1) cmH₂O; there was no correlation to expiratory flow and expiratory volume values.

DISCUSSION

Our study compared the PEP levels of improvised and commercial PEP devices through a range of expiratory volumes and flows, using a mechanical ventilator. Results demonstrate that the improvised “blow glove” device using latex gloves produces a higher percentage of in-range PEP levels across a wider range of expiratory flows and expiratory volumes than the commercial device.

Table 2 Percentage of “In Range” Positive Expiratory Pressure Measurements (10–20 cmH₂O) by PEP Device and Expiratory Flow Range

Device	No. (%) of in-range PEP values	
	Expiratory flow 10–80 L/min (n = 45)	Expiratory flow 10–40 L/min (n = 27)
Resistex level 1	5 (11.1)	5 (18.5)
Resistex level 2	8 (17.8)	8 (29.6)
Resistex level 3	9 (20.0)	9 (33.3)
Resistex level 4	7 (15.6)	7 (25.9)
Powdered glove (L)	37 (82.2)	19 (70.4)
Powdered glove (S)	40 (88.9)	22 (81.5)
Powder-free glove (L)	20 (44.4)	20 (74.1)

The “blow glove” device is easy to make and suitable for use by physical therapists in postoperative settings to increase pulmonary volume, decrease atelectasis, and promote secretion clearance, according to the rationale of the PEP technique.^{2,14} Mestriner et al.¹⁵ showed that when at least 8 mm of tubing was used, different tubing lengths produced no significant PEP pressure differences.

The Resistex expiratory resistance exerciser has four different fixed-orifice resistors that either the patient or the physical therapist can choose from, using a manom-

eter to measure active pressure during exhalation. This may explain why the proper therapeutic PEP levels can be achieved only within a narrow range of expiratory flows (10–20 L/min with resistor #1, 20 L/min with resistor #2, 20–30 L/min with resistor #3, and 40 L/min with resistor #4). The PEP levels produced by these four orifice resistors are only minimally affected by expiratory volumes (see Table 1). When a “blow bottle” PEP device with tubing and an air-escape orifice ≥ 8 mm is used, the device is acting as a threshold resistor (i.e., the PEP is generated only by the water column pressure and is not affected by air flows or expiratory volumes¹⁶). The “blow glove” device, on the other hand, uses the elasticity of the glove material to create PEP; it does not act as a fixed-orifice or threshold resistor. The “blow glove” PEP device we evaluated demonstrated the capacity to expand and, at the same time, to produce resistance that changes continuously as it expands, while maintaining a pressure range of 10–20 cmH₂O. We attribute these results to the elastic nature of the latex glove; the relatively lower elasticity of the powder-free glove probably contributed to the lower percentage of “in range” levels it produced.

We also found that PEEP values obtained using the improvised “blow glove” device are relatively stable and

- * Each boxplot represents positive expiratory level measured per each device in expiratory volume range of 400ml (bottom boxplot) to 2000ml (top boxplot).
- * The boxplots are divided into interquartile range, with the median value represented by the bold black line.
- * PEP therapeutic range (10–20 cm H₂O) is presented by the dotted lines.

Figure 2 Positive expiratory pressure (cmH₂O) level range in PEP devices at different expiratory flow (L/min) levels.

do not exceed 10cmH₂O even when the glove is inflated to 10 L. The “blow glove” device can maintain mean PEEP of 8 (SD 1) cmH₂O and holds similar PEP levels for at least 50–100 repetitions before reaching a pressure-level decrement of approximately 1 cmH₂O, which is considered clinically detrimental.

Limitations

Our study has several limitations. First, because the devices were tested using a ventilator with a limited expiratory volume range, we have no data on PEP levels for expiratory volumes >2000mL. Second, technical limitations precluded measurement of mean expiratory pressure and area under the curve for expiratory pressure, which would have allowed us to better assess PEP pattern differences between devices. Finally, our study did not involve human participants and therefore could not take respiratory variability into account. Future research should assess the safety, efficacy, and ease of use of improvised PEP devices in postoperative settings.

CONCLUSIONS

The “blow glove” improvised PEP device can produce therapeutic PEP levels (10–20 cmH₂O) for >70% of the expiratory flows and expiratory volumes reviewed, and thus has a higher percentage of “in range” PEP levels than the Resistex commercial device across similar expiratory flow and volume values.

Our current data with a mechanical ventilator support the use of any size of powdered latex gloves and show the efficacy of the “blow glove” PEP device, even when inflated with 10 L of air for 100 repetitions.

KEY MESSAGES

What is already known on this topic

Positive expiratory pressure (PEP) reduces early postoperative pulmonary complications by maintaining airway pressure of 10–20 cmH₂O during the middle part of expiration and preventing airway collapse. Target PEP range can be achieved with commercial or improvised devices.

What this study adds

An improvised “blow glove” device for postoperative chest physical therapy produces a significantly higher percentage of “in range” PEP levels than a commercial device. The improvised “blow glove” device using a powdered latex glove produces PEP levels in the target range significantly more often than the same device using a powder-free latex glove.

REFERENCES

1. Herdy AH, Marcchi PL, Vila A, et al. Pre- and postoperative cardio-pulmonary rehabilitation in hospitalized patients undergoing coronary artery bypass surgery: a randomized controlled trial. *Am J Phys Med Rehabil*. 2008;87(9):714–9. <http://dx.doi.org/10.1097/PHM.0b013e3181839152>. Medline:18716482
2. Öрман J, Westerdahl E. Chest physiotherapy with positive expiratory pressure breathing after abdominal and thoracic surgery: a systematic review. *Acta Anaesthesiol Scand*. 2010;54(3):261–7. <http://dx.doi.org/10.1111/j.1399-6576.2009.02143.x>. Medline:19878100
3. Renault JA, Costa-Val R, Rossetti MB. Respiratory physiotherapy in the pulmonary dysfunction after cardiac surgery. *Rev Bras Cir Cardiovasc*. 2008;23(4):562–9. Medline:19229431
4. Taggart DP, el-Fiky M, Carter R, et al. Respiratory dysfunction after uncomplicated cardiopulmonary bypass. *Ann Thorac Surg*. 1993;56(5):1123–8. [http://dx.doi.org/10.1016/0003-4975\(95\)90029-2](http://dx.doi.org/10.1016/0003-4975(95)90029-2). Medline:8239811
5. Fiore JF, Chiavegato LD, Paisani DM, et al. Utilization of positive-pressure devices for breathing exercises in the hospital setting: a regional survey in São Paulo, Brazil. *Respir Care*. 2010;55(6):719–24. Medline:20507654
6. Smetana GW. Postoperative pulmonary complications: an update on risk assessment and reduction. *Cleve Clin J Med*. 2009;76(Suppl 4):S60–5. <http://dx.doi.org/10.3949/ccjm.76.s4.10>. Medline:19880838
7. Pasquina P, Tramèr MR, Granier JM, et al. Respiratory physiotherapy to prevent pulmonary complications after abdominal surgery: a systematic review. *Chest*. 2006;130(6):1887–99. <http://dx.doi.org/10.1378/chest.130.6.1887>. Medline:17167013
8. Björkqvist M, Wiberg B, Bodin L, et al. Bottle-blowing in hospital-treated patients with community-acquired pneumonia. *Scand J Infect Dis*. 1997;29(1):77–82. <http://dx.doi.org/10.3109/00365549709008669>. Medline:9112303
9. Urell C, Emtner M, Hedenström H, et al. Deep breathing exercises with positive expiratory pressure at a higher rate improve oxygenation in the early period after cardiac surgery: a randomised controlled trial. *Eur J Cardiothorac Surg*. 2011;40(1):162–7. <http://dx.doi.org/10.1016/j.ejcts.2010.10.018>. Medline:21146420
10. Bott J, Blumenthal S, Buxton M, et al. Guidelines for the physiotherapy management of the adult, medical, spontaneously breathing patient. *Thorax*. 2009;64(Suppl 1):i1–52. <http://dx.doi.org/10.1136/thx.2008.110726>. Medline:19406863
11. Richter Larsen K, Ingwersen U, Thode S, et al. Mask physiotherapy in patients after heart surgery: a controlled study. *Intensive Care Med*. 1995;21(6):469–74. <http://dx.doi.org/10.1007/BF01706199>. Medline:7560489
12. Sehlén M, Ohlberg F, Johansson G, et al. Physiological responses to positive expiratory pressure breathing: a comparison of the PEP bottle and the PEP mask. *Respir Care*. 2007;52(8):1000–5. Medline:17650355
13. McCool FD, Rosen MJ. Nonpharmacologic airway clearance therapies: ACCP evidence-based clinical practice guidelines. *Chest*. 2006;129(1 Suppl):250S–9S. http://dx.doi.org/10.1378/chest.129.1_suppl.250S. Medline:16428718
14. Hofmeyr JL, Webber BA, Hodson ME. Evaluation of positive expiratory pressure as an adjunct to chest physiotherapy in the treatment of cystic fibrosis. *Thorax*. 1986;41(12):951–4. <http://dx.doi.org/10.1136/thx.41.12.951>. Medline:3296295
15. Mestriner RG, Fernandes RO, Steffen LC, et al. Optimum design parameters for a therapist-constructed positive-expiratory-pressure therapy bottle device. *Respir Care*. 2009;54(4):504–8. Medline:19327187
16. American Association for Respiratory Care. AARC clinical practice guideline: use of positive airway pressure adjuncts to bronchial hygiene therapy. *Respir Care*. 1993;38(5):516–21. Medline:10145836