Positive Expiratory Pressure to Enhance Cough Effectiveness in Tracheomalacia

Sanitra Sirithangkul MD*, Sarath Ranganathan MD**,
Philip J Robinson MD**, Colin F Robertson MD**

Poster presentation in the American Thoracic Society International Conference, May 2005, San Diego, USA.
** Department of Pediatrics, Phramongkutklao Hospital, Bangkok, Thailand*
***Respiratory Medicine, Royal Children's Hospital, Murdoch Children's Research Institute, Department of Pediatrics, University of Melbourne, Melbourne, Australia*

Objective: *To determine the effectiveness of increasing levels of Positive Expiratory Pressure (PEP) during coughing to enhance expiratory flow and improve efficiency of the cough.*
Material and Method: *Forty children aged 8 to 18 years, with repaired tracheo-oespohageal fistula (TOF) and twenty-one age matched controls performed spirometry followed by cough spirometry with PEP of 0, 5, 10, 15 and 20 cmH_2O using an adjustable PEP valve. Cough expiratory flow between 75 and 25 % of vital capacity (CEF_{25-75}) for each curve was calculated to represent the effectiveness of cough at mid-lung volume, the region of the flow volume curve most vulnerable in tracheomalacia.*
Results: *In the TOF group, CEF_{25-75} increased by a mean (95% CI) of 18.8% (4.4,33.2), 1.7% (-2.6,26.0) and 0.5% (-13.7,14.7) at PEP of 5,10 and 15 cmH_2O respectively, but decreased by 2.4% (-13.4,8.5) at PEP of 20 cmH_2O. In the control group the CEF_{25-75} decreased. The values were -3.1% (-16.7,10.4),-6.3%(-18.1,5.6), -22.2% (-33,-11.5) and –19%(-29.3,-8.7) at PEP of 5,10, 15 and 20cmH_2O respectively.*
Conclusion: *The use of a simple adjustable PEP valve increases CEF_{25-75} during cough spirometry and may provide a useful adjunct to chest physiotherapy in children with tracheomalacia.*

Keywords: *Tracheomalacia, Physiotherapy, Positive expiratory pressure, Cough spirometry*

J Med Assoc Thai 2010; 93 (Suppl. 6): S112-S118
Full text. e-Journal: *http://www.mat.or.th/journal*

Cough is a complex defence mechanism essential for clearing the airway of foreign bodies and to enhance the clearance of mucus from the tracheo-bronchial tree. During the explosive expiratory phase of cough, the high intra-pleural pressure causes dynamic compression of the central airways resulting in increased linear velocity which aids proximal clearance of airway secretions and debris. Cross-sectional area of the trachea may be reduced by up to 80%[1]. In subjects with tracheomalacia, there is instability of the tracheal wall such that during coughing, there is a more marked dynamic compression of the trachea that may impair rather than enhance the efficiency of the cough to clear mucus and results in the characteristic brassy cough.

Tracheomalacia is a common complication of oesophageal atresia with tracheo-oesophageal fistula (OA/TOF) with clinical manifestations ranging from the typical brassy cough to life-threatening apnoeic spells in severe cases. Survival of OA/TOF has significantly improved over the past 20 years[2], however, chronic suppurative lung disease is a common sequel.

Recurrent bronchitis occurs in up to 80% of infants and 25% of those over the age of 4 years[3]. In adults with repaired OA/TOF up to 24% report at least one episode of bronchitis per year[4].

Chest physiotherapy and effective cough are important for airway clearance during acute respiratory tract infections and particularly for those with chronic bronchitis or bronchiectasis.

Positive Expiratory Pressure (PEP) is used as an effective adjunct to physiotherapy to enhance airway clearance in those children[5-7] but PEP physiotherapy relies on a constant expiratory flow through a fixed resistor and has not been used as a method to support the intra-thoracic airway during cough. Continuous Positive Airway Pressure (CPAP)

Correspondence to:
Sirithangkul S, Department of Pediatrics, Phramongkutklao Hospital, Bangkok 10400, Thailand.
Phone: 0-2354-7600-28 ext. 94117
E-mail: sanitras@hotmail.com

has been demonstrated to support the airway in tracheomalacia during quiet breathing[8], but does not improve forced expiratory flows at mid lung volumes[9]. The aim of this study was to determine whether the use of constant PEP during coughing, independent of flow, may provide an internal air splint to reduce the dynamic compression of the trachea and enhance the cough velocity. Some of the results of this study have been previously reported in the form of an abstract[10].

Material and Method

Subjects

Children aged 8-18 years at the time of the study who were born with OA/TOF and had previously undergone corrective surgery at the Royal Children's Hospital were identified from a review of medical records. Children who had OA/TOF associated with other complex congenital abnormalities such as spinal deformity, congenital heart disease or neurological impairment were excluded from the study. Eligible subjects were invited to attend the pulmonary laboratory to complete a questionnaire about their current respiratory and gastrointestinal symptoms, to have a physical examination and tests of pulmonary function and cough spirometry. Current respiratory symptoms were defined as episodes of stridor, wheezing and/or dyspnoea, bronchitis or pneumonia in the 12 months before review. Current gastrointestinal symptoms were defined as difficulty in swallowing or regurgitation in the 12 months prior to review. Twenty-one age-matched children without respiratory disease were recruited from non-respiratory outpatient clinics. Informed consent was obtained from the parent and the child, where appropriate. The study was approved by the Hospital's Ethics in Human Research Committee.

Pulmonary function studies

Baseline spirometry and lung volumes were measured in a Jaeger Masterlab body plethysmograph (Jaeger, Hochberg, Germany) in accordance with the American Thoracic Society guidelines[11]. Measurements of pulmonary function were expressed as percent predicted for height and sex[12].

Cough spirometry

Cough spirometry was recorded and measured using the apparatus shown in Fig. 1. The equipment consisted of a mouthpiece connected via plastic tubing to a Hans Rudolph two-way non-rebreathing valve. The inspiratory limb of the valve was open to the atmosphere and the expiratory limb

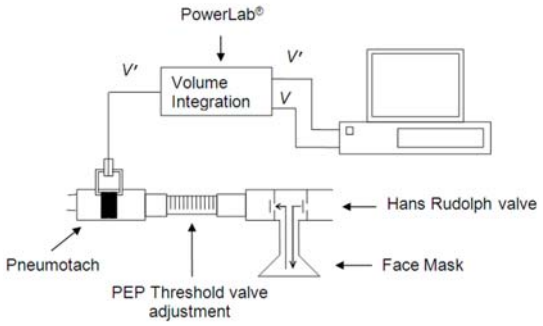

Fig. 1 Equipment for recording and measuring cough spirometry at different levels of PEP

connected to an adjustable PEP valve (Threshold™ PEP, Respironics Inc, New Jersey, USA) and a heated pneumotach (ADInstruments) which provided a constant pressure throughout expiration. A heated pneumotach was connected to and controlled by the PowerLab data acquisition system (ADInstruments Pty Ltd, New South Wales, Australia).

Each subject was studied seated, wearing a nose clip. Prior to cough spirometry, each subject was asked to perform three standard maximal expiratory flow-volume loops and the best flow-volume curve (largest sum of FVC and FEV_1) was selected for analysis[11]. Each subject was then asked to perform a series of coughs through the apparatus with PEP set at zero (baseline cough spirometry). The subject was instructed to inspire full to TLC then cough repeatedly and forcefully to residual volume, without intervening inspirations between the individual coughs. In all, three cough flow-volume curves were performed and the best selected for analysis. The expired volume of each cough flow-volume curve had to be at least 75% of baseline vital capacity and the best curve selected was that which gave the highest peak flow on the first cough.

The above procedures (3 maximal expiratory flow-volume loops followed by 3 cough flow-volume curves) were repeated with the subjects breathing out or coughing out through the apparatus against resistance resulting from PEP of 5, 10, 15 and 20 cmH_2O provided by the adjustable threshold PEP valve in random order.

Data analysis

The flow-volume loop was considered to be compatible with tracheomalacia if expiratory flow spiked at the beginning of expiration before flattening as expiration progressed[13]. The initial peak flow in

tracheomalacia remained normal during forced expiration or coughing.

This typical pattern of flow-volume curve suggests that mid-lung volume should represent the region that is flow limited during forced expiration in subjects with tracheomalacia. While the initial cough occurred at TLC, subsequent coughs occurred at different lung volumes. To overcome the inability to match coughs at the same lung volume, the expiratory flow between 75 and 25% of vital capacity was calculated from each cough spirometry flow-volume curve by dividing the volume expired between 75% and 25% of vital capacity by the time taken to expire this volume (CEF_{25-75}). This would represent the average flow for the coughs that occurred at mid lung volumes. As PEP may alter lung volume, the vital capacity measured at baseline (0 cmH_2O) was used as the reference to ensure that each CEF_{25-75} was measured at the same lung volume. Each cough flow volume was referenced to the same volume landmark irrespective of volume expired at the different levels of PEP. A similar approach was used to calculate FEF_{25-75} measured at different levels of PEP. Subsequently, the percentage increase in FEF_{25-75} and CEF_{25-75} over baseline at each level of PEP was calculated in order to determine the influence of increasing levels of PEP on expiratory flow during forced expiration and during coughing respectively. As the natural history and extent of tracheomalacia is variable in OA/TOF, two sub-groups were established based on the presence or absence of the characteristic brassy cough.

Statistical analysis

Data of baseline pulmonary function measurements were expressed as mean $\pm$ SD. The percentage increase in FEF_{25-75} and CEF_{25-75} from baseline (0 cmH_2O) at each level of PEP was expressed as mean and 95% confidence interval. Within each group, paired t-test was used to determine the significance of the difference from baseline. Comparisons between groups were made using unpaired t-tests. Analyses were performed using Stata 9 (Stata Corporation, Austin Texas). A p-value of less than 0.05 was considered to be statistical significance difference from baseline and between groups.

Results

One hundred and twenty-nine children with repaired OA/TOF were eligible for the study of which forty-three children consented to participate. Three children were subsequently excluded, as they were unable to perform cough spirometry. The anatomical diagnoses at presentation were OA with distal TOF in 35, TOF alone (H type) in 3 and OA alone in 2 children. Twenty of the TOF group (50%) continued to have the barking cough characteristic of tracheomalacia. Thirteen of the TOF subjects (33%) gave a history of at least one episode of bronchitis in the preceding 12 months with one subject reporting 5 episodes. Eight subjects (20%) had been diagnosed with asthma, but only two were on regular preventer therapy.

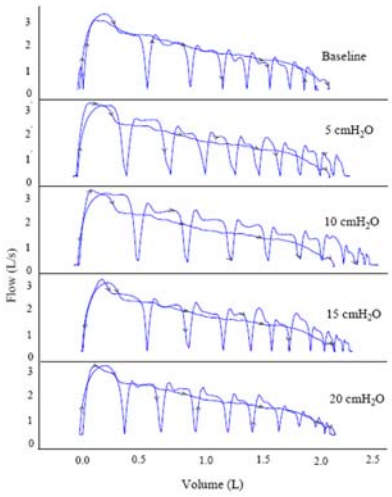

Fig. 2 Cough spirometry at each level of PEP superimposed on the baseline maximal expiratory flow-volume curve from a subject with TOF

Sixteen subjects (40%) had symptoms of swallowing difficulty but had no restriction in choice of foods. The characteristics and baseline pulmonary function measurements of both the subjects and the controls are shown in Table 1.

A series of cough spirometry curves at PEP levels of 0, 5, 10, 15 and 20 cmH_2O respectively superimposed on the baseline maximal expiratory flow volume curve from a subject with OA/TOF are shown in Fig. 2. The percentage increase in FEF_{25-75} from the flow-volume curve at baseline and the percentage increase in CEF_{25-75} from cough spirometry at baseline for each of the positive expiratory pressures are recorded in Table 2. At each level of PEP, there was a significant reduction in FEF_{25-75} in the controls, whereas there was no change in those with TOF/OA. Those subjects with TOF/OA who had no cough behaved similarly to the controls. The CEF_{25-75} at 5 cmH_2O was increased by 19% above the baseline value and by 12% at 10 cmH_2O of PEP. There was no significant

Table 1. Characteristics and baseline pulmonary function measurements of the TOF values expressed as mean ± SD, *p-value < 0.001

	TOF (n = 40)	Control (n = 21)	Mean difference (95% CI)
Age (years)	12.5 ± 2.7	13.1 ± 3.4	-0.6 (-2.2, 1.0)
Males	21	9	
FVC % pred	85.5 ± 16	103.6 ± 19.6	-18.1 (-24.5, -11.8)*
FEV_1 % pred	89.5 ± 17	112.0 ± 22.2	-22.6 (-29.8, -15.3)*
FEF_{25-75} % pred	79.2 ± 22.9	113.6 ± 29.9	-34.4 (-48.9, -20.7)*
FEV_1/FVC%	88.7 ± 8.2	91.2 ± 15.9	-2.5 (-6.0, 1.0)
TLC% pred	102.5 ± 15	115 ± 22.5	-12.7 (-19.3, -6.1)*
RV% pred	163.3 ± 37.4	166 ± 43.7	-2.9 (-21.2, 15.4)
RV/TLC%	38.5 ± 8.6	34.5 ± 7.8	4.0 (-0.3, 8.3)

TOF = tracheo-oesophageal fistula

Table 2. Percentage increase over baseline and 95%CI in FEF_{25-75} and CEF_{25-75} at each level of PEP in the overall TOF group, the subgroup of children with barking cough, the subgroup of children without barking cough and the control group. *p-value < 0.05

	PEP ($cm H_20$)	All TOF n = 40	Cough n = 20	No cough n =20	Control n = 21	Mean difference TOF v controls (95%CI)
FEF_{25-75}						
	5	-1.7 (-7.5, 4.2)	2.9 (-6.2, 12.0)	-6.2 (12.4,-0.1)	-8.7 (-15.1,-2.3)	7.1 (-1.3, 15.4)
	10	-1.7 (-9.2, 5.8)	7.3 (-3.3, 17.8)	-10.6 (-19.3,-1.9)	-10.0 (-16.7,-3.4)	8.4 (-1.4, 18.1)
	15	-3.6 (-9.5, 2.3)	-0.4 (-9.6, 8.8)	-6.8 (-13.4, -0.3)	-13.1 (-19.8, -6.4)	9.5 (1.0, 17.9*)
	20	0.5 (-6.4, 7.40	8.8 (-0.5, 18.2)	-7.8 (-16.3, 0.6)	-11.5 (-20.2, -2.9)	12.0 (1.0, 23.1*)
CEF_{25-75}						
	5	18.8 (4.4, 33.2)	19.4 (0.8, 37.9)	18.3(-3.6, 40.1)	-3.1 (-16.7, 10.5)	21.9* (1.5, 42.3)
	10	11.7 (-2.6, 26.0)	16.9 (-0.2, 34.1)	6.5 (-16.2, 29.1)	-6.3 (-18.1, 5.6)	18.0 (-1.2, 37.1)
	15	0.5 (-13.7, 14.7)	8.7 (-11.3, 28.7)	-6.8 (-13.4, -0.3)	-22.2 (-33, -11.5)	22.7 (4.8, 40.6*)
	20	-2.4 (-13.4, 8.5)	3.7 (-12.5, 19.8)	-8.5 (-22.7, 5.6)	-19.0 (-29.3, -8.7)	16.6 (1.5, 31.6*)

TOF = tracheo-oesophageal fistula

improvement in cough flow at the higher pressures (Fig. 3). The controls had no change in CEF_{25-75} at lower pressures but had a significant reduction in cough flows at the higher levels of PEP.

Discussion

The study has shown that in those with TOF, CEF_{25-75} increased during cough spirometry at PEP levels of 5 and 10 cmH_2O. In contrast, CEF_{25-75} decreased at each level of PEP, particularly at PEP of 15 and 20 cmH_2O in the control group. There was no significant change from FEF_{25-75} at baseline (0 cmH_2O) and at each level of PEP of 5,10,15 and 20 cmH_2O, in the total TOF group or the subgroup of children with characteristic barking cough. However, FEF_{25-75} significantly decreased at each level of PEP in the control group.

Previous studies of cough spirometry have tended to concentrate on the ratio of maximum expiratory flow obtained during forced expiration to cough peak flow at the same lung volume (the cough ratio). The cough ratio has been shown to decline during adult life in healthy adults[14] and in asthmatic children[15] and may be related to alterations in airway compliance and cross-sectional area of the airways. In 2002, Chaudri et al reported that patients with neuromuscular disease who were unable to generate

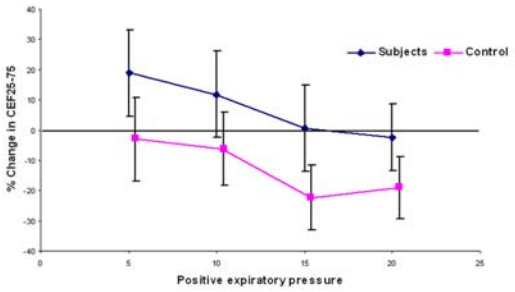

Fig. 3 The percentage increase in CEF_{25-75} from baseline (0 cmH_2O) at each level of PEP in the TOF group and the control group. Mean ± SEM

supramaximal flow during cough had poorer lung function and higher mortality[16]. Analysis of cough flow-volume curves has been done previously by superimposing a maximum expiratory flow-volume curve on the cough flow-volume curve of the same subject. Then, a line has been drawn by eye through all cough peak flows (except the first one) and the cough ratio calculated from this line at any given lung volume [14]. In the current study, due to the variability in cough peak flows, we were unable to use this method. We studied the cough flow-volume curve at baseline and different levels of PEP, as PEP may alter lung volume therefore we were unable to use the cough ratio to compare each curve. Hence, we calculated CEF_{25-75} from each cough flow-volume curve by referencing to the vital capacity (VC) measurement obtained from the baseline flow-volume curve.

Children with tracheomalacia have potentially impaired cough efficiency, however, no previous study has investigated cough spirometry or the effect of PEP during coughing in this particular group of children. Children with tracheomalacia usually have a flaccid region of the trachea that easily collapses when transmural airway pressure decreases in the presence of increasing intrapleural pressure, particularly during forced expiration or coughing. This interferes with the effective cough mechanism.

The PEP that is traditionally used for chest physiotherapy techniques is generated as a patient exhales through a fixed orifice resistor. The pressure generated by such a resistor is flow dependent. The size of the expiratory orifice is selected to match the expiratory flow of the individual patient targeting an expiratory pressure of 5-20 cmH_2O. PEP has been identified as an effective physiotherapy technique for splinting the airways during expiration and preventing air trapping[17] but its flow dependent nature renders it inappropriate to use during coughing. Threshold PEP has a flow independent one-way valve which provides constant resistance throughout the respiratory cycle of the cough. Therefore, the use of Threshold PEP during coughing may benefit the child with tracheomalacia by providing a functional airway stent. In the TOF group, at the low pressures of 5 and 10 cmH_2O, it is likely that Threshold PEP acts as a stent maintaining airway patency at the site of flow-limitation within the trachea, thus permitting higher flow to be generated during the cough. At pressures above this level, the airways of TOF subjects appear to have the same response as healthy airways, that is, as the resistance to airflow increases with rise in PEP, peak cough flows fall accordingly and negate the benefit of tracheal splinting. An increase in PEP above 10 cmH_2O appears to be ineffective in improving cough efficiency even in the subgroup of children who had characteristic barking cough. In this study, we did not observe any significant changes in FEF_{25-75} when PEP was applied in either the TOF group as a whole or in the subgroup of children who had characteristic barking cough. Once sufficient pressure has been generated to produce maximum expiratory flow during a forced expiratory manoeuvre, further increases in pressure will not result in increased flow as described previously[18]. Ideally, we would like to have used an oesophageal manometer to estimate pleural pressure but the procedure was felt to be too invasive which would have jeopardized recruitment of subjects into the study. In the control group, FEF_{25-75} decreased significantly at each level of PEP which can be predicted as an increase in resistance at the airway opening results in a reduction in forced expiratory driving pressure.

Our results suggest therefore, it is the combined effects of coughing and increased resistance to flow which are effective at splinting the trachea in those with TOF. Beyond threshold driving pressure, the factors that determine maximum flow at any given lung volume are the cross- sectional area of the airway and the compliance of the airway wall[19]. In those with tracheomalacia, PEP at 5 and 10 cmH_2O increased flow at mid-lung volume perhaps by decreasing airway wall compliance and splinting the flow-limiting segment of the trachea. The main purpose of cough is to clear secretions and foreign bodies from the large airways. The effectiveness and efficiency of cough have been shown to depend on the sustained flow rate during a cough and the shape and size of the airway[20]. Both of these components are likely to be influenced by

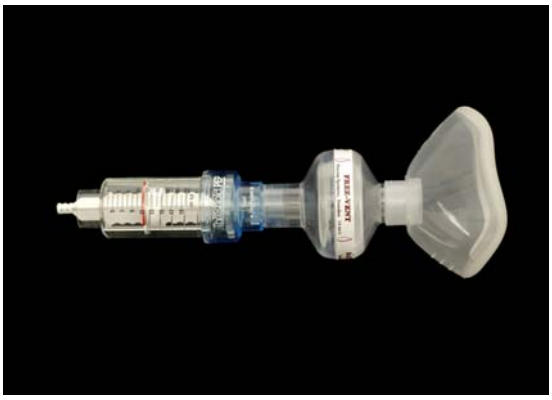

Fig. 4 Illustration of clinical device including mask, filter and Threshold valve

Threshold PEP in those with TOF. A clinical system has been developed (Fig. 4) which, in clinical practice, has been effective in improving sputum clearance in those children with tracheomalacia and suppurative lung disease. In conclusion, we have demonstrated a significant increase in CEF_{25-75} during cough spirometry at low levels of PEP in children with tracheomalacia which is likely to improve cough effectiveness. The application of a simple adjustable threshold PEP valve, with an optimal level of PEP between 5 and 10 cmH_2O during coughing, may provide a useful adjunct to chest physiotherapy in children with tracheomalacia.

Acknowledgement

The study was funded by the Oesophageal Atresia Research Association, Victoria, Australia. Sanitra Sirithangkul was funded by The Children's Foundation, Phramongkutklao Hospital, Bangkok, Thailand.

The authors thank Dr Ric Roberts, Mr. Liam Welsh and Ms. Marisol Pineiro for their help in pulmonary function testing.

References

1. Leith DE, Butler JP, Sneddon SL, Brain JD. Cough. In: Macklem PT, Mead J, editors. Handbook of physiology. Section 3: The respiratory system. Washington, DC: American Physiological Society; 1986: 315-36.
2. Choudhury SR, Ashcraft KW, Sharp RJ, Murphy JP, Snyder CL, Sigalet DL. Survival of patients with esophageal atresia: influence of birth weight, cardiac anomaly, and late respiratory complications. J Pediatr Surg 1999; 34: 70-3.
3. Couriel JM, Hibbert M, Olinsky A, Phelan PD. Long term pulmonary consequences of oesophageal atresia with tracheo-oesophageal fistula. Acta Paediatr Scand 1982; 71: 973-8.
4. Chetcuti P, Myers NA, Phelan PD, Beasley SW. Adults who survived repair of congenital oesophageal atresia and tracheo-oesophageal fistula. BMJ 1988; 297: 344-6.
5. Groth S, Stafanger G, Dirksen H, Andersen 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: 339-43.
6. Van Asperen PP, Jackson L, Hennessy P, Brown J. Comparison of a positive expiratory pressure (PEP) mask with postural drainage in patients with cystic fibrosis. Aust Paediatr J 1987; 23: 283-4.
7. McIlwaine PM, Wong LT, Peacock D, Davidson AG. Long-term comparative trial of conventional postural drainage and percussion versus positive expiratory pressure physiotherapy in the treatment of cystic fibrosis. J Pediatr 1997; 131: 570-4.
8. Okazaki J, Isono S, Hasegawa H, Sakai M, Nagase Y, Nishino T. Quantitative assessment of tracheal collapsibility in infants with tracheomalacia. Am J Respir Crit Care Med 2004; 170: 780-5.
9. Davis S, Jones M, Kisling J, Angelicchio C, Tepper RS. Effect of continuous positive airway pressure on forced expiratory flows in infants with tracheomalacia. Am J Respir Crit Care Med 1998; 158: 148-52.
10. Sirithangkul S, Welsh L, Roberts RG, Burge A, Robinson PJ, Robertson CF. Positive expiratory pressure to enhance cough effectiveness in children with tracheomalacia. Am J Respir Crit Care Med 2005; 171: A472.
11. Standardization of Spirometry, 1994 Update. American Thoracic Society. Am J Respir Crit Care Med 1995; 152: 1107-36.
12. Zapletal A, Motoyama EK, Van De Woestijne KP, Hunt VR, Bouhuys A. Maximum expiratory flow-volume curves and airway conductance in children and adolescents. J Appl Physiol 1969; 26: 308-16.
13. Hyatt RE. Evaluation of major airway lesions using the flow-volume loop. Ann Otol Rhinol Laryngol 1975; 84: 635-42.
14. Beardsmore CS, Wimpress SP, Thomson AH, Patel HR, Goodenough P, Simpson H. Maximum voluntary cough: an indication of airway function. Bull Eur Physiopathol Respir 1987; 23: 465-72.
15. Beardsmore CS, Park A, Wimpress SP, Thomson

AH, Simpson H. Cough flow-volume relationships in normal and asthmatic children. Pediatr Pulmonol 1989; 6: 223-31.
16. Chaudri MB, Liu C, Hubbard R, Jefferson D, Kinnear WJ. Relationship between supramaximal flow during cough and mortality in motor neurone disease. Eur Respir J 2002; 19: 434-8.
17. Fink JB. Positive pressure techniques for airway clearance. Respir Care 2002; 47: 786-96.
18. Hyatt RE, Flath RE. Relationship of air flow to pressure during maximal respiratory effort in man. J Appl Physiol 1966; 21: 477-82.
19. Hyatt RE. Expiratory flow limitation. J Appl Physiol 1983; 55(1 Pt 1): 1-7.
20. Lawson TV, Harris RS. Assessment of the mechanical efficiency of coughing in healthy young adults. Clin Sci 1967; 33: 209-24.

แรงดันบวกในช่วงการหายใจออกเพื่อทำให้ประสิทธิภาพของการไอในโรค tracheomalacia ดีขึ้น

สนิตรา ศิริธางกูล, สาราธ รังกานาธาน, ฟิลิป โรบินสัน, คอลิน โรเบิร์ตสัน

วัตถุประสงค์*: เพื่อศึกษาถึงประสิทธิภาพของการเพิ่มระดับของแรงดันบวกในช่วงการหายใจออกขณะไอต่ออัตราความเร็ว และประสิทธิภาพของการไอ*

วัสดุและวิธีการ*: ผู้ป่วยเด็กโรค tracheomalacia ที่ได้รับการผ่าตัดแก้ไข อายุ 8-18 ปี จำนวน 40 คน และกลุ่มควบคุมจำนวน 21 คนที่อายุใกล้เคียงกัน ได้รับการตรวจสมรรถภาพปอด และตรวจสมรรถภาพปอดด้วยการไอ (cough spirometry) ขณะใช้แรงดันบวกในช่วงการหายใจออกที่ 0, 5, 10, 15 และ 20 เซนติเมตรน้ำ โดยใช้อุปกรณ์ที่ปรับระดับแรงดันบวกในช่วงการหายใจออกได้ คำนวณอัตราความเร็วเฉลี่ยของการไอ เพื่อแสดงประสิทธิภาพของการไอในขณะที่ปริมาตรปอดมีขนาดปานกลาง ซึ่งเป็นตำแหน่งที่หลอดลมถูกทำให้ยุบตัวง่ายที่สุดในผู้ป่วยโรค tracheomalacia*

ผลการศึกษา*: ในกลุ่มที่ทำการศึกษาพบว่าอัตราความเร็วเฉลี่ยของการไอเพิ่มขึ้น (95% CI) ร้อยละ 18.8 (4.4, 33.2), ร้อยละ 1.7 (-2.6, 26.0), ร้อยละ 0.5 (-13.7, 14.7) เมื่อใช้แรงดันบวกในช่วงการหายใจออกที่ 5, 10, 15 เซนติเมตรน้ำตามลำดับ แต่ลดลงร้อยละ 2.4 (-13.4, 8.5) เมื่อใช้แรงดันบวกในช่วงการหายใจออกที่ 20 เซนติเมตรน้ำ ในกลุ่มควบคุมอัตราความเร็วเฉลี่ยของการไอลดลง ร้อยละ -3.1 (-16.7,10.4), ร้อยละ -6.3 (-18.1,5.6), ร้อยละ -22.2 (-33,-11.5) และร้อยละ -19 (-29.3,-8.7) เมื่อใช้แรงดันบวกในช่วงการหายใจออกที่ 5, 10, 15 และ 20 เซนติเมตรน้ำตามลำดับ*

สรุป*: การใช้อุปกรณ์ง่าย ๆ ที่สามารถปรับแรงดันบวกในช่วงการหายใจออก ช่วยเพิ่มอัตราความเร็วเฉลี่ยของการไอขณะตรวจสมรรถภาพปอดด้วยการไอ และอาจเป็นอุปกรณ์ที่มีประโยชน์ใช้ช่วยในการทำกายภาพบำบัดทรวงอกผู้ป่วยเด็กโรค tracheomalacia*