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RESEARCH PAPER

Efficacy of short-term intrapulmonary percussive ventilation in patients with chronic obstructive pulmonary disease

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Abstract

Purpose: We evaluated the effectiveness of intrapulmonary percussive ventilation (IPV) compared to traditional standard chest physical therapy (CPT) in patients with chronic obstructive pulmonary disease (COPD) and productive cough.

Methods: We conducted a quasi-experimental clinical trial. Twenty patients, 40% female (mean ± SD age: 70 ± 8 years), with COPD and productive cough received a multimodal respiratory treatment including IPV and CPT or a control intervention CPT for 10 days. Outcomes: P_{Imax}, P_{Emax}, heart rate, respiratory rate, SBP, DBP, Likert scale, Borg dyspnea scale and arterial blood gas analysis: PO_2, PCO_2, pH, HCO_3 and SpO_2 measurements. All measures were collected at baseline and at the end of the intervention. We used repeated ANOVA to examine the effects of interventions within groups, between-subjects and the within-subjects.

Results: A significant effect of time interaction ($F = 7.27$; $p = 0.015$, $F = 6.16$; $p = 0.02$ and $F = 7.41$; $p = 0.014$) existed for PO_2, SpO_2 and dyspnea over the moderate COPD and productive cough immediately after the intervention (all, $p < 0.02$). Both treatments are similarly effective in P_{Imax} and P_{Emax}. No significant group effect or group-by-time interaction was detected for any of them, which suggests that both groups improved in the same way.

Conclusions: This study provides evidence that a short-term combination of IPV and CPT improves PO_2, SpO_2 and perceived dyspnea than a traditional standard CPT in patients with COPD and productive cough.

Keywords

Chest, chronic obstructive pulmonary disease, intrapulmonary percussive ventilation, physical therapy

History

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➤ Implications for Rehabilitation

- We suggest that it could improve the oxygenation level on chronic obstructive pulmonary disease (COPD) patients. Beyond that, the intrapulmonary percussive ventilation (IPV) is a safety non-pharmacologic airway clearance therapy that can be used on patients with different sorts of respiratory diseases, and there are still questions to be answered, especially concerning the volume of secretion removed and its superiority when compared with other techniques.

Introduction

Chronic obstructive pulmonary disease (COPD) is a chronic, life-threatening lung disease and the third leading cause of death worldwide [1], characterized by chronic airflow limitation and a range of pathophysiological lung modifications followed by significant extra pulmonary effects [2]. The pulmonary rehabilitation program (PRP) is a multidisciplinary intervention for COPD patients, focused mainly on exercise training, education and psychological support. The conventional chest physiotherapy (CPT) comprises five separate elements introduced by the Cystic Fibrosis Foundation in 1997 [3] as: postural drainage (PD), percussion (P), vibration (V), deep breathing and directed cough (DC). It is commonly used to improve mucus clearance and to previne pulmonary infections on patients with acute or chronic respiratory disease. It is historically consisted as the combination of the forced expiration techniques described before, but nowadays is classified as a non-pharmacologic airway clearance therapy with some adverse effects and not totally supported by well designed clinical trials [4,5].

The combination of these rehabilitation approaches is important in the treatment of COPD patients to avoid respiratory complications, as lung collapse and secretion retention and to improve the prognosis, health status and respiratory function [6].

Assisted mucus-clearing techniques are usually performed daily by skilled physiotherapists and include forced expiratory technique, assisted cough, mechanical insufflation–exsufflation, breathing techniques and air stacking [7–9].

Intrapulmonary percussive ventilation (IPV) is mechanical device, designed to deliver intermittent high-frequency positively

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pressurized bursts of gas, on the airway creating a internal percussion on the lungs. It was first used by respiratory therapist/physiotherapist for secretion removal in patients with Duchenne muscular dystrophy [10], cystic fibrosis [11] or atelectasis [12,13]. In patients with bronchiectasis and productive cough, the short-term IPV was described as safe and effective as the CPT, and it was defined as a more comfortable airway cleaning therapy [14].

The presence of airway secretion is a main component of the COPD's physiopathology [15], so the airway clearance therapies plays an important role on the rehabilitation of such patients. Our objective on this research was to evaluate the effect of the IPV's addition on a PRP, on COPD's patients with productive cough recovered in a general rehabilitation center.

Methods

Study design

We conducted a quasi-experimental clinical trial. Informed consent was obtained from all participants and procedures were conducted according to the Declaration of Helsinki.

Patients

We screened 30 patients and enrolled 11 men and nine women, aged 51 to 80 years old, from January 2011 to June 2011. The COPD was diagnosed according to the GOLD criteria [2], by the referent pneumologist and the patients were classified as having moderate-to-severe airway obstruction. All patients were clinically stable and they all underwent subjective and objective physical examination performed by an expert respiratory physiotherapist. Patients were asked not to take analgesics, muscle relaxants or anti-inflammatory drugs for 24 h prior to the examination.

The inclusion criteria were: a diagnosis of COPD; daily sputum volume >20 mL for at least five consecutive days and hemodynamic stability. The exclusion criteria were: cardiac arrhythmias, hemodynamic instability, respiratory failure or the need of invasive or non-invasive mechanical ventilation, sepsis, sensory abnormalities, history of recent spontaneous pneumothorax, or costal fractures, skeletal muscles dysfunction or orthopedic impairments and tracheostomy. We also excluded patients who did not sign the informed consent.

Protocol

All the patients enrolled were submitted to a PRP consisted on continuous aerobic training, on treadmill, twice a day, five days a week, target on 60 to 70% of maximal heart rate determined as 220 – age. The patients also comprised a daily 30 min callisthenic group gymnastic. The patients included in this study, also followed a non-pharmacological airway clearance therapy protocol (NACTP), consisted on the conventional CPT techniques as: slow expiratory with glottis opened in lateral position (ELTGOL) [16], positive expiratory pressure (PEP) mask [17], or bottle [18] forced expiration and instructed cough [19]. The patients were assigned to experimental ($n = 10$) and control ($n = 10$) treatment groups with simple randomization.

Experimental group

The patients in the experimental group received the multimodal treatment described above and the IPV. The NACTP were applied daily, over a period of 10 days. First the patient received 10 min of conventional CPT and then IPV for 15 min.

IPV protocol. The IPV utilization followed a protocol previously published [14] and was performed with aerosol therapy. Each IPV session included three active cycles, including two phases at low pressure and high frequency, and another phase at high pressure and low frequency with the patient in a sitting position. At the end of each cycle the respiratory therapist required the patient to cough. We used the IPV®-2C *IPV Impulsator* (Percussionaire® Corporation, Sandpoint, ID).

Control group. Patients in the control group received the same number of treatment sessions of a similar duration as those in the experimental group but they only received the conventional CPT application for 25 min. The techniques were applied by an expert respiratory physiotherapist. If the patient was on supplemental oxygen, the oxygen flow was maintained constant during treatments.

Outcomes and measurements. Pre-treatment measurements were collected by an assessor blinded to the subjects' intervention assignment. The pre-treatment measurements were taken in the following order: the P_{Imax}, P_{Emax}, SpO_2, heart rate, respiratory rate, systolic arterial blood pressure (SABP), diastolic arterial blood pressure (DABP) and the perception of the dyspnea, measured by the Modified Borg Scale (MBS), and arterial blood gas analyses (ABGA): pH, PO_2, PCO_2, HCO_3 and SpO_2. After pre-treatment measurements, subjects were assigned by arrival order, into the two groups. Subjects received the 10 treatments, from a respiratory physiotherapist blinded to the subjects' pre-treatment measurements. Post-treatment testing were performed 5 min after the application of the last procedure by the same assessor that took the pre-treatment measurement, and who remained blinded to the treatment allocation of the subject. The present document was prepared according to the editorial form of medical publishing and STROBE publishing rules [20]. All outcomes were collected by an external assessor blinded to the treatment allocation of the participants.

Outcome measures

At baseline we recorded demographics, anthropometry, respiratory and cardiac function, P_{Imax}, P_{Emax}, SpO_2, heart rate, respiratory rate, P_{Amax}, P_{Amin}, PO_2, PCO_2, pH, HCO_3 and the patient's subjective sensation of dyspnea. Before each treatment session (time zero [T0]) and immediately after the session (T1).

Statistical analysis

Data were analyzed using SPSS version 20.0 (SPSS Inc, Chicago, IL), conducted following an intention-to-treat analysis using the last value forward method. Group data were summarized using means and standard deviations. The Kolmogorov–Smirnov test confirmed the normality of the distribution of the data. The Student *t*-test was used to determine the level of significance of the differences between the pre- and post-treatment measurements. We used a 2×2 repeated measures analysis of variance (ANOVA) to determine the differences in time (pre-intervention and post-intervention) as the within-subjects factor and group (experimental or control) as the between-subjects factor. The main hypothesis of interest was Group × Time interaction. Between-group differences were expressed as mean differences with 95% CIs. Between-groups effect sizes were calculated using Cohen's *d* coefficient. An effect size greater than 0.8 was considered large, around 0.5 moderate, and less than 0.2 small. In all analyses, $p < 0.05$ was considered statistically significant.

Results

Thirty ($n = 30$) consecutive subjects with COPD were screened for eligibility criteria. Twenty patients (mean ± SD age: 70 ± 8

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years; 40% female) satisfied all eligibility criteria, agreed to participate. We have assigned 10 patients to the control group and other 10 patients to the experimental group. The reasons for ineligibility were hemodynamic instability ($n=5$), the need of non-invasive mechanical ventilation ($n=3$), and the concurrent presence of major cardiac arrhythmias ($n=2$). None of the subjects had modified the regular pharmacologic therapy during the study. The anthropometric characteristics were similar between groups, (Table 1). Table 2 shows the cardiac and respiratory function baseline characteristics. Also those parameters did not show significant statistical differences between the control and intervention group (Table 1).

Response to treatment

Outcomes for P_{Imax} and P_{Emax} demonstrated a significant time factor ($F=36.579$; $p<0.001$ and $F=15.229$; $p<0.001$, respectively). The inspiratory and expiratory respiratory muscle strength increased for all participants after the treatment period. The *post-hoc* analysis revealed significant differences between the 10 sessions for the treatment group ($p<0.001$ and $p=0.004$) and for the control group ($p=0.016$ and $p=0.039$). Between-groups effect sizes were moderate at post-treatment period ($d<0.8$).

Table 1. Baseline demographics for both groups[a].

	Experimental ($n=10$)	Control ($n=10$)	p Value[b]
Age (years)	70 ± 10	71 ± 5	0.76
Male gender [n (%)]	5 (50%)	6 (60%)	0.74
Height (cm)	166.3 ± 9.5	166.0 ± 7.7	0.99
Weight (kg)	66.7 ± 16.3	87.2 ± 19.1	1.12
pH	7.5 ± 0.1	7.5 ± 0.1	0.4
PaO_2 (mmHg)	60.9 ± 11.3	64.7 ± 10.4	0.4
$PaCO_2$ (mmHg)	48.2 ± 8.5	46.4 ± 12.3	0.7
HCO_3 (mmHg)	35.6 ± 6.6	32.9 ± 5.6	0.3
SpO_2 (%)	91.0 ± 5.9	93.1 ± 3.6	0.35
PI max (cmH_2O)	52.3 ± 36.4	40.0 ± 17.2	0.35
PE max (cmH_2O)	79.2 ± 32.8	65.2 ± 27.4	0.31
Modified Borg Scale	1.6 ± 1.8	3.0 ± 1.8	0.96
Respiratory rate (breaths/min)	17.3 ± 4.5	19.1 ± 5.5	0.56
Heart rate (beats/min)	87.2 ± 16.1	83.0 ± 8.9	0.48
Likert scale	2.7 ± 0.5	2.8 ± 0.6	0.97
SBP (mmHg)	120.5 ± 10.1	118.5 ± 16.0	0.97
DBP (mmHg)	67.5 ± 6.3	64 ± 9.7	0.96

cm: centimeters; kg: Kilograms; mmHg: millimeter of mercury; cmH_2O: centimeters of water; pH: hydrogen ionic potential; PaO_2: Arterial partial pressure of oxygen; $PaCO_2$: Arterial partial pressure of carbon dioxide; HCO_3: bicarbonate; SpO_2: Oxygen saturation as measured by pulse oximetry; P_{Imax}: maximum inspiratory pressure; P_{Emax}: maximum expiratory pressure; SBP: Systolic blood pressure; DBP: Diastolic blood pressure.

[a]Data are expressed as means ± standard deviations (SD).

[b]p Value for Student's t-test.

Arterial blood gases

For the arterial blood gases measured over the PaO_2 and SpO_2 were no significant group-by-time ($F=0.06$; $p=0.81$ and $f=1.54$; $p=0.2$, respectively) interaction. There was also significant main effect for time ($F=7.27$; $p=0.015$ and $F=6.16$; $p=0.02$, respectively). The *post-hoc* analysis indicated that the patients on the intervention group improve the oxygenation, increasing significantly the PaO_2 and SpO_2 compared to those receiving the control intervention immediately post-intervention; experimental group, −8.4; 95% CI: −16.9, 0.1, $p=0.05$ and −0.04; 95% CI: −0.07, −0.01, $p=0.017$, respectively). Between-groups effect sizes were small at post-treatment period ($d<0.2$).

There were no other significant modification for the other arterial blood gases. The pH measures revealed significant differences for the treatment group ($p=0.001$) and for the control group ($p=0.024$), but these modifications did not expressed any important clinical issue.

Dyspnea

Regarding the results of the MBS, the ANOVA test revealed a significant effect of time ($F=7.41$; $p=0.014$) but not for group-by-time interaction ($F=1.53$; $p=0.2$) for dyspnea. The *post-hoc* analysis indicated that the patients, on the intervention group, indicated a lower score on the MBS. Clinically this improvement did not mean a reduction in the perception of the dyspnea, even when compared to the score indicated in the control group. These results were confirmed on our *post-hoc* analysis revealing a significant difference for the treatment group ($p=0.01$) and nothing else.

Discussion

Our study combined the IPV and the CPT as an adjunctive therapy of a PRP, on moderate to severe COPD patients, with productive cough. Our main findings were: the combination of the IPV and CPT improve PaO_2, SpO_2. Otherwise, we also observed improvements on the maximal inspiratory and expiratory pressures on patients from control and experimental groups.

On COPD patients, the lung secretion retention is a common problem, with important repercussion on the lung function as consolidation/atelectasis and quality of life. The respiratory

Table 2. Mean (SD) for outcome at all study visits for each group, mean (SD) difference within groups, and mean (95% CI) difference between groups.

	Groups				Difference within groups		Difference between groups
	Day 0		Day 10		Day 10 minus Day 0		Day 10 minus Day 10
Outcome	Exp ($n=10$)	Con ($n=10$)	Exp ($n=10$)	Con ($n=10$)	Exp ($n=10$)	Con ($n=10$)	Exp minus Con
pH	7.46 (0.03)	7.45 (0.03)	7.44 (0.03)	7.44 (0.03)	−0.02[a] (0.01)	−0.01[a] (0.01)	0.003 (−0.03 to 0.03)
PaO_2	60.9 (11.3)	64.7 (10.4)	69.3 (8.7)	71.7 (10.0)	8.4 (4.0)	7.0 (4.0)	2.4 (−7.2 to 12.0)
SpO_2	0.95 (0.04)	0.95 (0.03)	0.99 (0.02)	0.97 (0.03)	0.03[a] (0.01)	0.02 (0.01)	−0.02[b] (−0.04 to 0.001)
HCO_3	35.6 (6.6)	32.9 (5.6)	34.6 (6.9)	33.7 (4.8)	−1.0 (1.5)	0.79 (1.5)	−0.9 (−6.54 to 4.70)
P_{Imax}	52.3 (36.4)	40.0 (17.2)	65.1 (32.6)	45.8 (119.5)	12.8[a] (2.2)	5.8[a] (2.2)	19.3 (−6.0 to 44.6)
P_{Emax}	79.2 (32.8)	65.2 (27.5)	91.6 (26.4)	73.6 (29.2)	12.4[a] (3.8)	8.4[a] (3.8)	18 (−8.2 to 44.2)
Borg scale	1.6 (1.8)	3.0 (1.8)	1.0 (1.3)	1.4 (1.7)	−0.6 (0.6)	−1.6 (0.6)	−0.4 (−1.8 to 1.0)

pH: hydrogenionic potential; PaO_2: Arterial partial pressure of oxygen; SpO_2: Oxygen saturation as measured by pulse oximetry; HCO_3: bicarbonate; P_{Imax}: maximum inspiratory pressure, P_{Emax}: maximum expiratory pressure.

[a]Significantly different within-group, $p<0.05$ (95% confidence interval).

[b]Significant difference between-group, $p<0.05$ (95% confidence interval).

physiotherapists have several instruments to help the patients to remove the retained secretion and to educate the patient to do it properly. The IPV was considered a novel instrument to help on achieving this goal, especially on patient with cystic fibrosis. This device has few contraindications and is easy to handle by the physiotherapist. On the other hand, the CPT also improves mucus transport, but it is still controversial when considering which group of patient has benefit from which CPT modalities [5,10].

The combination of both techniques on the intervention group achieves improvements on the arterial blood gas analyses and the dyspnea, showing an oxygenation improvement on patients who presented hypoxemia on their admittance before the beginning of the PRP. Concerning the dyspnea sensation: The MBS is a reliable scale to use in this context [21] and even on acute exacerbated COPD patients [22]. Our results, despite the statistical finding, does not support us to agree with a recent paper that demonstrates the dyspnea improvement after the use of the IPV [14]. First, our findings showed that our patients stated not more than a "slight breathlessness" on the beginning and in the end of the protocol, and second, the work of Paneroni et al. [14] assessed the dyspnea with a visual analogue scale and we used the MBS. Differently from the same research and other trial on Duchene patients [10], we observed an increase in SpO_2 and PaO_2 and a trial on patients admitted in intensive care unit [23], also showed improvements on the PaO_2. There is also other aspect that differences our study from those, we used the IPV in stable admitted patients, so they were not critically ill, and they also underwent a PRP. The patients experienced an IPV's long-term utilization, and our study had a larger number of patients enrolled when compared with the study of Toussaint et al. [10], and was similar from those of Paneroni et al. [14].

The maximal inspiratory and expiratory pressure increases were a very important issue founded on our results. As we know, these parameters until now, were not tested as a IPV outcome as we did. It is known that the cough, on COPD's patients is fundamental on the protection and airway cleaning and an ineffective cough may lead to lungs secretion retention [4]. On moderate stage COPD patients, these parameters are also strongly correlated and predictive to lung functional parameters as the Forced Expiratory Volume on one second, Peak Expiratory Flow, Forced Vital Capacity and Total Lung Capacity. The respiratory muscular strength is a useful outcome used to determine whether the cough is effective or not [24] (in this case we consider the maximal expiratory pressure) and is associated with the increasing inspiratory capacity [6] (considering maximal inspiratory pressure). We observed that both parameters increased on the experimental and control group. So, in this case, we cannot discuss that the addition of the IPV on a PRP that involves the conventional CPT lead, itself on the improvements of the respiratory pressures.

Actually the PRP may be a bias on our results. It is known that the pulmonary rehabilitation has their principal benefits on the improvement of the respiratory and peripheral muscular strength, reduction dyspnea and improvements on gas exchange [6]. Other important limitation of our study was the fact that we did not measured the volume of the secretion expectorated. Despite the fact that we analyzed a small sample, it is important to say that on our trial, we achieve interesting results on the gas exchange variables that similar studies did not found, but we must mention that our sample size is far from the ideal. Additionally, we are aware that we only examined the mid short-term effects of IPV directed at the COPD and productive cough. Therefore, we cannot affirm that the positive results will remain on time.

There are no evidence from randomized controlled trials to support the use of ACT to improve oxygenation, resolve atelectasis/consolidations or respiratory mechanics where the CPT has been mistakenly classified as the gold standard therapy for airway clearance [4]. On the presented context, our research, opens a track for researches on the utilization of the IPV as a part of the pulmonary rehabilitation program, especially for patients with productive cough. Certainly, future researches shall be more controlled, as on a clinical trial design.

Implications for the respiratory rehabilitation

The IPV is a safety non-pharmacologic airway clearance therapy that can be used on patients with different sorts of respiratory diseases, and there are still questions to be answered, especially concerning the volume of secretion removed and its superiority when compared with other techniques.

Conclusion

This study provides evidence that on patients who underwent a pulmonary rehabilitation program, with moderate COPD and productive cough, the combination of IPV and CPT may improve PO_2, SpO_2 and dyspnea, than only a traditional standard CPT. Both treatments are similarly effective in P_{Imax} and P_{Emax}. However, the treatment approach has limited value in improving heart rate, respiratory rate, as well as, PCO_2 and HCO_3. These results confirm the potential benefit of the utilization of the IPV on the PRP for such patients. We recommend further large, high-quality, randomized controlled studies of such techniques to demonstrate their validity, including measure of lung function and long-term follow-up outcomes.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

1. Hakimi AA, Furberg H, Zabor EC, et al. An epidemiologic and genomic investigation into the obesity paradox in renal cell carcinoma. J Natl Cancer Inst 2013;105:1862–70.
2. Brito-Mutunayagam R, Appleton SL, Wilson DH, et al. Global Initiative for Chronic Obstructive Lung Disease stage 0 is associated with excess FEV(1) decline in a representative population sample. Chest 2010;138:605–13.
3. An introduction to Postural Drainage & Percussion [internet]. Cystic Fibrosis Foundation (CFF); 2005. Available from: http://www.cff.org/UploadedFiles/treatments/Therapies/Respiratory/PosturalDrainage/An%20Introduction%20to%20Postural%20Drainage%20and%20Percussion%201-2006.pdf [last accessed 28 Jul 2010].
4. Strickland SL, Rubin BK, Drescher GS, et al. AARC clinical practice guideline: effectiveness of nonpharmacologic airway clearance therapies in hospitalized patients. Resp Care 2013;58:2187–93.
5. van der Schans CP. Conventional chest physical therapy for obstructive lung disease. Resp Care 2007;52:1198–206; discussion 206–9.
6. Ries AL, Bauldoff GS, Carlin BW, et al. Pulmonary rehabilitation: joint ACCP/AACVPR evidence-based clinical practice guidelines. Chest 2007;131:4S–42S.
7. Bach JR. Update and perspective on noninvasive respiratory muscle aids. Part 2: the expiratory aids. Chest 1994;105:1538–44.
8. Kang SW, Bach JR. Maximum insufflation capacity: vital capacity and cough flows in neuromuscular disease. Am J Phys Med Rehabil 2000;79:222–7.

DOI: 10.3109/09638288.2014.948130

9. Pryor JA. Physiotherapy for airway clearance in adults. Eur Resp J 1999;14:1418–24.
10. Toussaint M, De Win H, Steens M, Soudon P. Effect of intrapulmonary percussive ventilation on mucus clearance in Duchenne muscular dystrophy patients: a preliminary report. Resp Care 2003;48:940–7.
11. Velmahos GC, Chan LS, Tatevossian R, et al. High-frequency percussive ventilation improves oxygenation in patients with ARDS. Chest 1999;116:440–6.
12. Paulsen SM, Killyon GW, Barillo DJ. High-frequency percussive ventilation as a salvage modality in adult respiratory distress syndrome: a preliminary study. Am Surgeon 2002;68:852–6; discussion 6.
13. Natale JE, Pfeifle J, Homnick DN. Comparison of intrapulmonary percussive ventilation and chest physiotherapy. A pilot study in patients with cystic fibrosis. Chest 1994;105:1789–93.
14. Paneroni M, Clini E, Simonelli C, et al. Safety and efficacy of short-term intrapulmonary percussive ventilation in patients with bronchiectasis. Resp Care 2011;56:984–8.
15. Viegi G, Pistelli F, Sherrill DL, et al. Definition, epidemiology and natural history of COPD. Eur Resp J 2007;30: 993–1013.
16. Nicolini A, Cardini F, Landucci N, et al. Effectiveness of treatment with high-frequency chest wall oscillation in patients with bronchiectasis. BMC Pulm Med 2013;13:21.
17. West K, Wallen M, Follett J. Acapella vs. PEP mask therapy: a randomised trial in children with cystic fibrosis during respiratory exacerbation. Physiother Theory Pract 2010;26:143–9.
18. Sehlin M, Ohberg F, Johansson G, et al. Physiological responses to positive expiratory pressure breathing: a comparison of the PEP bottle and the PEP mask. Resp Care 2007;52:1000–5.
19. Hasani A, Pavia D, Agnew JE, et al. Regional lung clearance during cough and forced expiration technique (FET): effects of flow and viscoelasticity. Thorax 1994;49:557–61.
20. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting of observational studies. Der Internist 2008;49:688–93.
21. Crisafulli E, Clini EM. Measures of dyspnea in pulmonary rehabilitation. Multidiscipl Resp Med 2010;5:202–10.
22. Kendrick KR, Baxi SC, Smith RM. Usefulness of the modified 0–10 Borg scale in assessing the degree of dyspnea in patients with COPD and asthma. JEN 2000;26:216–22.
23. Vargas F, Bui HN, Boyer A, et al. Intrapulmonary percussive ventilation in acute exacerbations of COPD patients with mild respiratory acidosis: a randomized controlled trial [ISRCTN17802078]. Crit Care 2005;9:R382–9.
24. Terzano C, Ceccarelli D, Conti V, et al. Maximal respiratory static pressures in patients with different stages of COPD severity. Resp Res 2008;9:8(1–7).