

Intrapulmonary percussive ventilation improves the outcome of patients with acute exacerbation of chronic obstructive pulmonary disease using a helmet*

Vittorio Antonaglia, MD; Umberto Lucangelo, MD; Walter A. Zin, MD, DSc; Alberto Peratoner, MD; Loredana De Simoni, MD; Guido Capitanio, MD; Sara Pascotto, MD; Antonino Gullo, MD

Objective: To evaluate the effect of intrapulmonary percussive ventilation (IPV) by mouthpiece during noninvasive positive-pressure ventilation with helmet in patients with exacerbation of chronic obstructive pulmonary disease (COPD).

Design: Randomized clinical trial.

Setting: General intensive care unit, university hospital.

Patients: Forty patients with exacerbation of COPD ventilated with noninvasive positive-pressure ventilation by helmet were randomized to two different mucus clearance strategies: IPV (IPV group) vs. respiratory physiotherapy (Phys group). As historical control group, 40 patients receiving noninvasive positive pressure and ventilated by face mask treated with respiratory physiotherapy were studied.

Interventions: Two daily sessions of IPV (IPV group) or conventional respiratory physiotherapy (Phys group).

Measurements and Main Results: Physiologic variables were measured at entry in the intensive care unit, before and after the first session of IPV, and at discharge from the intensive care unit. Outcome variables (need for intubation, ventilatory assistance, length of intensive care unit stay, and complications) were also

measured. All physiologic variables improved after IPV. At discharge from the intensive care unit, $Paco_2$ was lower in the IPV group compared with the Phys and control groups (mean \pm SD, 58 ± 5.4 vs. 64 ± 5.2 mm Hg, 67.4 ± 4.2 mm Hg, $p < .01$). Pao_2/FiO_2 was higher in IPV (274 ± 15) than the other groups (Phys, 218 ± 34 ; control, 237 ± 20 ; $p < .01$). In the IPV group, time of noninvasive ventilation (hrs) (median, 25th–75th percentile: 61, 60–71) and length of stay in the intensive care unit (days) (7, 6–8) were lower than other groups (Phys, 89, 82–96; control, 87, 75–91; $p < .01$; and Phys, 9, 8–9; control, 10, 9–11; $p < .01$).

Conclusions: IPV treatment was feasible for all patients. Noninvasive positive-pressure ventilation by helmet associated with IPV reduces the duration of ventilatory treatment and intensive care unit stay and improves gas exchange at discharge from intensive care unit in patients with severe exacerbation of COPD. (Crit Care Med 2006; 34:●●●–●●●)

KEY WORDS: noninvasive ventilation; helmet; chronic respiratory failure; pressure support ventilation; respiratory physiotherapy; intrapulmonary percussive ventilation

It has been demonstrated that first-line intervention with noninvasive positive-pressure ventilation (NPPV) can reverse acute respiratory failure in a significant number of patients with exacerbation of chronic obstructive pulmonary disease (COPD), and NPPV can be considered the ventilatory mode of choice in selected patients experiencing COPD exacerbations (1–8).

Recently, a new helmet has been proposed to provide NPPV to these patients (9). The patients treated with the helmet presented better tolerance and fewer complications in comparison to those treated with standard facial mask, but the value of $Paco_2$ was constantly higher in the helmet group. The authors reported that the hypercapnia was not associated with helmet CO_2 rebreathing but probably was attributable to a less efficient reduction of the inspiratory effort during NPPV due to a partial dissipation of the inspiratory pressure in the soft part of the helmet, thus thwarting the patient-machine synchrony. They concluded that NPPV with helmet can be used for patients with less severe acute exacerbation of COPD. In those cases it would be preferable to apply NPPV by using a facial mask, and, indeed, a recent study supports this hypotheses (10). On the other hand, the advantages of the helmet in

clinical practice are evident in terms of comfort and tolerability (9). Intrapulmonary percussive ventilation (IPV) delivers high-frequency mini-bursts of flow at the mouth superimposed on the spontaneous breathing pattern, thus associating convective flow (intermittent positive-pressure ventilation) with high-frequency oscillations (diffusive flow) and improving gas exchange and elimination of secretions. IPV has been used in patients with cystic fibrosis (11, 12), Duchenne muscular dystrophy (13), and atelectasis (14, 15).

The role of physical and respiratory therapies in patients with severe acute exacerbation of COPD requiring NPPV is not clearly established. However, it has been recently demonstrated that physiotherapy benefit these patients (16). Among the mucus clearance strategies based on high-frequency oscillation, IPV represents a potentially good but not well-explored technique.

***See also p. xx.**

From the Department of Perioperative Medicine, Intensive Care and Emergency, Cattinara Hospital, Trieste University School of Medicine, Trieste, Italy, and Carlos Chagas Filho Institute of Biophysics, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil.

The authors have not disclosed any potential conflicts of interest.

Copyright © 2006 by the Society of Critical Care Medicine and Lippincott Williams & Wilkins

DOI: 10.1097/01.CCM.0000248725.15189.7D

Hence, in a prospective and controlled trial, we randomized 40 patients with acute exacerbation of COPD, treated with NPPV by helmet, into two different groups of mucus clearance strategies: IPV vs. physical and respiratory therapy. We assessed as the primary end point the feasibility of IPV and the effect of the first session of IPV on gas exchange immediately after discontinuation of the NPPV helmet. The second aim of the study was to investigate the clinical events (need of intubation, duration of supported ventilation, length of ICU stay, complications) connected to the time course of the exacerbation of COPD in two groups.

MATERIALS AND METHODS

Patients and Design of the Study. Forty consecutive adult patients admitted to the intensive care unit (ICU) of Cattinara Hospital from January to September 2003 with acute exacerbation of COPD were studied in the semirecumbent position. The diagnosis of COPD was made according to clinical history, physical examination, and chest radiography. The patients met the following criteria for NPPV: They were admitted to ICU within a maximum of 12 hrs of admission to the emergency department and were tachypneic with a respiratory rate of >25 breaths/min, a pH of 7.10–7.35, and a $P_{aCO_2} >50$ mm Hg. Additional criteria for enrollment were those proposed by Brochard et al. (2) and included an exacerbation of dyspnea lasting <2 wks and at least two of the following: respiratory rate >30 breaths/min, $P_{aO_2} <45$ mm Hg, and arterial pH <7.35 after breathing at $F_{iO_2} <0.35$ for ≥ 10 mins. Exclusion criteria were a) a Glasgow Coma Scale score <8 ; b) failure of more than two additional organs; c) severe hemodynamic instability defined as systolic blood pressure <0 mm Hg; d) electrocardiogram instability with evidence of ischemia or significant ventricular arrhythmia; and e) requirement for sudden intubation for cardiopulmonary resuscitation. No patients received active humidification. The Acute Physiology and Chronic Health Evaluation II score was determined 24 hrs after the admission to the ICU.

At admission the patients were randomly divided into two groups of 20 patients each by another physician unaware of the study: a) those undergoing standard helmet-NPPV and respiratory physiotherapy (Phys group) and b) those who would receive helmet-NPPV and noninvasive IPV via a mouthpiece (IPV group). The randomization was provided by a computer software on a patient-by-patient basis.

As first-line treatment, all patients received helmet-NPPV and medical therapy (i.e., oxygen therapy, nebulized β_2 -agonists, systemic corticosteroids, diuretics, and antibiotics as required). We used a helmet (CaStar; Starmed,

Mirandola, Italy) provided with antiasphyxia mechanisms. The inflatable cushion at the level of the soft collar of the helmet avoided air leakage, which was further ensured by the increased adherence of the collar to the neck during the mounting up of inspiratory pressure. The other characteristics of the helmet were identical to those previously reported (9). A 7200 Puritan-Bennett ventilator (Puritan-Bennett Corporation, Carlsbad, CA) delivered intermittent positive-pressure ventilation to the helmet with the initial settings of 15 cm H_2O inspiratory positive airway pressure and 5 cm H_2O of positive end-expiratory pressure in pressure support mode triggered by flow-by. The baseline pressure support level was raised in steps of 2 cm H_2O to obtain patient comfort, reduce the respiratory rate to <30 breaths/min (17), and eliminate accessory muscle activity (18). The flow trigger was used at 3–5 L/min with a basal flow of 15–20 L/min. F_{iO_2} was used to maintain a peripheral oxygen saturation $>90\%$ as measured by pulse oximetry (Viridia M3, Hewlett-Packard GmbH, Boeblingen, Germany). All patients were monitored with continuous electrocardiography and pulse oximetry and repeated measurements of arterial blood gases (Radiometer ABL 300, Copenhagen, Denmark) to adjust the ventilator setting.

After the first 2 hrs of NPPV, the pH level and the clinical status were used to decide the need for intubation: If dyspnea and pH remained unchanged in relation to the evaluation at the beginning of NPPV, the patients were intubated and ventilated and, thus, eliminated from the study; otherwise they continued under NPPV. In the latter condition the inspiratory pressure was adjusted according to the patient's tolerance to obtain a respiratory rate <25 breaths/min and the disappearance of accessory muscle activity, as evaluated by palpating the sternocleidomastoid muscle (18). NPPV was delivered almost continuously in the first 24 hrs with short intervals of spontaneous breathing with oxygen supplementation and aerosol therapy.

In the second day, and henceforth, NPPV was used in a sequential mode according to Hilbert et al (4). Periods of 3–4 hrs of ventilation were alternated with 2–3 hrs of spontaneous breathing with controlled oxygen therapy. Patients in the Phys group underwent a 25- to 30-min session of standard respiratory physiotherapy (chest clapping, mobilization and postural drainage, and expiration with the glottis open in the lateral posture, 10 mins each), whereas patients in the IPV group received two 25- to 30-min sessions of IPV (via a mouthpiece) with a IPV-1 Percussionator (Percussionaire Corporation, Sandpoint, ID) and a Phasitron DUO (Percussionaire Corporation). The patients breathed through a mouthpiece that delivered high-flow mini-bursts at rates of 225 cycles per minute. IPV was applied during spontaneous inspiration with a peak delivery pressure <40 cm H_2O . During respiratory physiotherapy, the thera-

pists were instructed to alert the physician when heart rate, mean arterial pressure, and respiratory rate changed $>25\%$ of the basal values and when severe dyspnea or peripheral oxygen saturation $<85\%$ was present. During IPV, hemodynamic status, respiratory rate, and peripheral oxygen saturation were continuously monitored. The patients were returned to NPPV when peripheral oxygen saturation was $<85\%$ or when respiratory rate became >30 breaths/min (4).

Invasive mechanical ventilation was substituted for NPPV right after the initial session of NPPV or during sequential mode in the following circumstances: a) increase in respiratory rate and gas exchange deterioration; b) development of conditions requiring tracheal intubation to protect the airways; c) deterioration of neurologic status with a Glasgow Coma Scale score <8 ; d) intolerance to the helmet fixation stripes; and e) major agitation requiring sedation. The patients were intubated with a Rusch cuffed tracheal tube (inner diameter, 7.5–8.0 mm) and ventilated (7200 Puritan-Bennett Ventilator, Puritan-Bennett Corporation, Carlsbad, CA) in the semirecumbent position under pressure support ventilation with positive end-expiratory pressure.

In both groups of patients we determined duration of mechanical ventilation, length of ICU stay, need for tracheostomy, and ICU mortality rate. We evaluated the presence of a) pneumonia (a new lung infiltrate on the chest radiograph associated with at least two of the following conditions: fever, leukocytosis, or purulent sputum in which a Gram-negative stain showed one or more types of bacteria) not present at admission (nosocomial pneumonia); b) sepsis syndrome defined as positive blood cultures and fever of $>39^\circ C$ together with positive cultures from suspected sources; and c) metabolic complications (hyponatremia: $Na <120$ mmol/L or serum potassium levels <3 mmol/L or >6 mmol/L, alkalosis or metabolic acidosis, fasting hyperglycemia >160 mg/dL).

The criteria to determine when ventilator assistance was discontinued were the following: normal mental status, hemodynamic stability, respiratory rate <25 breaths/min, absence of activation of accessory muscles of respiration and paradoxical abdominal motion, arterial pH >7.33 , $P_{aCO_2} <70$ mm Hg, $P_{aO_2} >55$ mm Hg, and $F_{iO_2} >0.35$ without ventilatory support. The patients were discharged from the ICU when NPPV was switched to oxygen therapy with $F_{iO_2} <0.35$ for ≥ 24 hrs and the patients met the following criteria: cardiorespiratory stability, respiratory rate <20 breaths/min, pH >7.35 , $P_{aO_2} >55$ mm Hg, $P_{aCO_2} <70$ mm Hg, and absence of fever, leukocytosis, purulent sputum, and metabolic complications. An independent clinical team not involved in the research protocol determined discharge.

Another group of 40 patients (controls) were selected from a population of patients admitted to the ICU in the period 2001–2003

with a diagnosis of respiratory failure due to acute exacerbation of COPD. They had the same criteria of enrollment, discontinuation of ventilation, and discharge from the ICU as the IPV and Phys groups. These patients were treated with facial mask NPPV delivered by the same ventilator and similar settings, under-vent respiratory physiotherapy, and were clinically treated as those in the other two groups. The physician who selected the controls was not involved in the study and was not informed about the course of treatment. For each patient in groups IPV and Phys, one matching control was selected according to the following criteria: age within 10 yrs and severity of illness at admission as assessed by Acute Physiology and Chronic Health Evaluation II within 5 points of the treated patients; Paco_2 and arterial pH at admission within 10 mm Hg and 0.05 points of the values of the treated patients; and $\text{PaO}_2/\text{FiO}_2$ (during oxygen therapy by a Venturi mask) within 25 points of the treated patients. When matching each patient, we based the relative importance of each factor on the coefficients of priority attributed to Paco_2 , pH, age, Acute Physiology and Chronic Health Evaluation II, and $\text{PaO}_2/\text{FiO}_2$. The patients' characteristics are listed in Tables 1 and 2.

The investigation was approved by the local Ethics Committee, and informed consent was obtained from each individual or his or her next of kin.

Statistical Analysis. One-way analysis of variance was used to compare continuous variables among groups; when normality test failed (Kolmogorov-Smirnov test), Kruskal-Wallis nonparametric test was used. Chi-square test (or Fisher's exact test when appropriate) was applied for categorical data. Student's *t*-test for paired data (or Wilcoxon's nonparametric test) was used to compare pre-post treatment. All statistical computations were performed with Sigma Stat 3.11 (Systat Software, Point Richmond, CA) statistical software.

The null hypothesis was rejected with $\alpha = .05$.

RESULTS

Table 1 shows the anthropometric and functional characteristics of COPD patients at admission to the ICU. No differences among the three groups were detected. Fourteen, 13, and 21 patients in the IPV, Phys, and control groups, respectively, were hypersecretive, that is, produced ≥ 30 mL of secretion per day. PaO_2 and Paco_2 in steady state (not considered in the design of the study) were available for 18 patients of 20 in the IPV group, 17 patients of 20 in the Phys group, and 36 patients of 40 in control group. The mean (\pm SD) values of PaO_2 and Paco_2 were 58 ± 5 and 55 ± 6

Table 1. Anthropometric and functional characteristics of patients with chronic obstructive pulmonary disease at admission

	Phys Group		IPV Group		Control Group		<i>p</i> Value
Age, yrs ^a	69	7	72	7	69	6	NS ^b
Height, cm ^a	1.71	0.19	1.69	0.09	1.68	0.11	NS ^b
Weight, kg ^a	67	7	70	10	68	8	NS ^b
RR, min ^c	31	29–33	33	30–35	33	29–34	NS ^d
pH ^a	7.21	0.06	7.22	0.05	7.21	0.03	NS ^b
Paco_2 , mm Hg ^a	80	6.5	79	7	78	5.6	NS ^b
$\text{PaO}_2/\text{FiO}_2$ ^a	163	33.3	173	27.1	181	29	NS ^b
Pa_{mean} , mm Hg ^a	96	8.6	93	7.8	95	7	NS ^b
APACHE II ^c	22	20–26	22	20–26	22	21–24	NS ^d

Phys, physiotherapy; IPV, intrapulmonary percussive ventilation; NS, not significant; RR, respiratory rate; Pa_{mean} , mean arterial pressure; APACHE, Acute Physiology and Chronic Health Evaluation. ^aMean, SD; ^bone-way analysis of variance; ^cmedian, 25th–75th percentile; ^dKruskal-Wallis ranks test. Patients were randomized at admission to two groups: The Phys group underwent helmet and noninvasive positive pressure ventilation plus respiratory physiotherapy, the IPV group was submitted to helmet and noninvasive positive pressure ventilation plus IPV, and the control group was treated with noninvasive positive pressure ventilation with facial mask plus respiratory physiotherapy.

Table 2. Values of physiologic variables at discharge from intensive care unit

	Phys Group		IPV Group		Control Group		<i>p</i>
pH ^a	7.38	0.02	7.39	0.02	7.37	0.01	NS ^b
Paco_2 , mm Hg ^a	64	5.2	58	5.4	67	4	<.01 ^b
$\text{PaO}_2/\text{FiO}_2$ ^a	218	34.2	274	14.8	237	20	<.01 ^b
RR, min ^c	25	24–26	24	22–24	24	23–25	NS ^d
Pa_{mean} , mm Hg ^a	81	3.4	82	3.6	83	4	NS ^b
HR, min ^c	81	71–89	81	80–85	87	78–90	NS ^d

Phys, physiotherapy; IPV, intrapulmonary percussive ventilation; NS, not significant; RR, respiratory rate; Pa_{mean} , mean arterial pressure; HR, heart rate.

^aMean, SD; ^bone-way analysis of variance; ^cmedian, 25th–75th percentile; ^dKruskal-Wallis ranks test. Significant differences in IPV group vs. the other groups. The Phys group underwent helmet and noninvasive positive pressure ventilation plus respiratory physiotherapy, the IPV group was submitted to helmet and noninvasive positive pressure ventilation plus IPV, and the control group was treated with noninvasive positive pressure ventilation with facial mask plus respiratory physiotherapy.

mm Hg in the IPV group, 57 ± 4 and 54 ± 5 mm Hg in the Phys group, and 59 ± 5 and 56 ± 6 mm Hg in the control group, respectively.

After the first 2 hrs under helmet plus NPPV, five patients from the Phys group, six from the IPV group, and 12 individuals using facial mask required intubation and mechanical ventilation. On the second day, different treatment strategies were applied to Phys and IPV groups; that is, the former received respiratory physiotherapy and the latter intrapulmonary percussive ventilation; the control group differed from the first solely on the interface between ventilator and airways (Phys group = helmet; control group = facial mask). Until discharge, two, one, and nine patients required intubation and mechanical ventilation (Phys, IPV, and control groups, respectively) because of impairment of gas exchange (two patients)

and intolerance to either the helmet (two patients) or the mask (eight patients).

Table 2 lists the physiologic variables determined when the patients were discharged from the ICU. The IPV group presented lower Paco_2 and higher $\text{PaO}_2/\text{FiO}_2$ than the other two groups, which were not different. Table 3 shows that IPV patients were discharged with a shorter duration of ventilatory assistance and stay in the ICU than the other two groups, whereas no differences were found in need of intubation and complications.

The mean values of pressure support ventilation and positive end-expiratory pressure were not different in the groups (19.6 ± 4.3 and 7.2 ± 2.2 cm H₂O in the Phys group, 19.1 ± 4.5 and 7.0 ± 2.5 cm H₂O in the IPV group, and 19.4 ± 4.4 and 7.1 ± 2.4 cm H₂O in the control group, respectively).

Table 3. Characteristics and outcome variables in patients with acute exacerbation of chronic obstructive pulmonary disease

	Phys Group		IPV Group		Control Group		<i>p</i>
Patients requiring intubation ^a	7	35	7	35	21	53	NS ^b
Ventilatory assistance, hrs ^c	89	82–96	61	60–71	87	75–91	<.01 ^d
Length of ICU stay, days ^c	9	7.75–9.5	7	6–8	10	9–11	<.01 ^d
Metabolic complications ^a	4	20	4	20	12	30	NS ^e
Sepsis and pneumonia ^a	4	20	2	10	11	28	NS ^e
Tracheostomy ^a	0	—	0	—	3	8%	NS ^e

Phys, physiotherapy; IPV, intrapulmonary percussive ventilation; NS, not significant; ICU, intensive care unit.

^an, %; ^bχ² test; ^cmedian, 25th–75th percentile; ^dKruskal-Wallis ranks test; ^eFisher's exact test. Significant differences in IPV group in relation to the other groups. The Phys group underwent helmet and noninvasive positive pressure ventilation plus respiratory physiotherapy, the IPV group was submitted to helmet and noninvasive positive pressure ventilation plus IPV, and the control group was treated with noninvasive positive pressure ventilation with facial mask plus respiratory physiotherapy.

Table 4. Gas exchange values before and after the first application of intrapulmonary percussive ventilation

	Pre		Post		<i>p</i>
pH ^a	7.31	0.03	7.34	0.04	<.01 ^b
Paco ₂ , mm Hg ^a	68.1	4.9	60.6	5.8	<.01 ^b
PaO ₂ /Fio ₂ ^a	226	32	267	24	<.01 ^b
Pa _{mean} , mm Hg ^a	89.5	6	83	6	.02 ^b
RR, min ^c	28	27.5–29	24	22–24.5	<.01 ^d
HR, min ^c	93	90–97.5	81	80–85	.02 ^d

Pa_{mean} mean arterial pressure; RR, respiratory rate; HR, heart rate.

^aMean, SD; ^bStudent's *t*-test for paired samples; ^cmedian, 25th–75th percentile; ^dWilcoxon vs signed-rank test.

In all instances, IPV did not yield general complications as aerophagia, regurgitation, hemodynamic impairment, and hemorrhage. Additionally, pH, Paco₂, PaO₂/Fio₂, respiratory and heart rates, and mean arterial pressure improved significantly after the first session of IPV (Table 4).

DISCUSSION

The potential benefit of mucus clearance strategies by physical and respiratory therapies in the management of patients with severe acute exacerbation of COPD has not been clearly established (19). In trials with patients under oxygen therapy or during invasive ventilation, these techniques were found ineffective and even detrimental (20–22). To our knowledge, no studies have reported ineffectiveness or detrimental effects of respiratory physiotherapy in COPD patients during noninvasive ventilation. Indeed, many works report an increase in gas exchange by mechanically assisted cough or other methods of mucus clearance during noninvasive ventilation (23–26).

Finally, Bellone et al. (16) demonstrated that physiotherapy was efficient in removing bronchial secretions in patients with acute exacerbation of COPD during noninvasive ventilation.

Although the application of NPPV by means of a helmet has been recently reported in the treatment of patients with acute exacerbations of COPD, it was concluded that the technique is feasible but less efficient in carbon dioxide elimination in comparison with NPPV and face mask (9). However, we hypothesized that, since IPV improves gas exchange in lung disease such as cystic fibrosis (10–12), Duchenne muscular dystrophy (13), and atelectasis (14, 15) and improves secretion mobilization and clearance in COPD patients (27), it could also be useful in the acute exacerbation of COPD in patients treated with helmet instead of face mask, which has been considered as the gold standard for treatment.

High-frequency oscillation is believed to improve mucus clearance by means of a variety of mechanisms (28). Another important beneficial feature of IPV is the improvement in gas exchange, and differ-

ent mechanisms exist to explain gas transport under these conditions (29–32). IPV would improve gas exchange as a result of both convective and diffusive mechanisms, possibly increasing the ventilation/perfusion relationship of the lung. Intrapulmonary percussive ventilation delivers high-frequency mini-bursts of flow at the mouth superimposed on the spontaneous breathing pattern. It thus associates convective flow (intermittent positive-pressure ventilation) with high-frequency oscillations (diffusive flow), as can be seen in Fig. 1. IPV associates the positive aspects of NPPV with those of the high-frequency ventilation.

The use of NPPV and helmet in COPD patients was introduced by Antonelli et al (9). They reported that 30.3% of their patients failed this technique. In our experiment, we found an overall value of 35%, a value close to that previously reported (9). It must be stressed that the rate of failure was identical in both helmet groups. Finally, NPPV used with a facial mask yields a worse clinical outcome than the helmet in acute hypoxemic respiratory failure (33); we also verified in our facial mask ventilated control group a worse outcome in patients with exacerbation of COPD (21 of 40 patients), as shown in Table 2. It can thus be suggested that the helmet-NPPV can be used as a first-line approach in COPD patients, keeping in mind that about one fourth of them will require an invasive approach (11 of 40 patients were intubated within 2 hrs).

To our knowledge, there is no previous study associating helmet-NPPV and IPV to treat acute bouts of COPD. Our data demonstrate that two daily sessions of IPV were able to improve the clinical conditions of the patients faster (less time under helmet-NPPV, shorter stay in the ICU; Table 3) and to a larger extent (smaller Paco₂ and higher PaO₂/Fio₂; Table 4) than the patients of Phys and control groups, which presented similar results.

Two mechanisms to facilitate mucus clearance by high-frequency oscillation have been proposed. First, there could be an increased mucus/flow interaction leading to a decrease in the mucus viscoelasticity (34); second, the transient changes in air flow with each high-frequency cycle could produce shearing at the air-mucus interface and provide a cough-like force to the mucus layer (32, 35). Additionally, gas exchange could be improved by high-frequency oscillation as a result of a redistribution of lung volume by increasing the volume of air

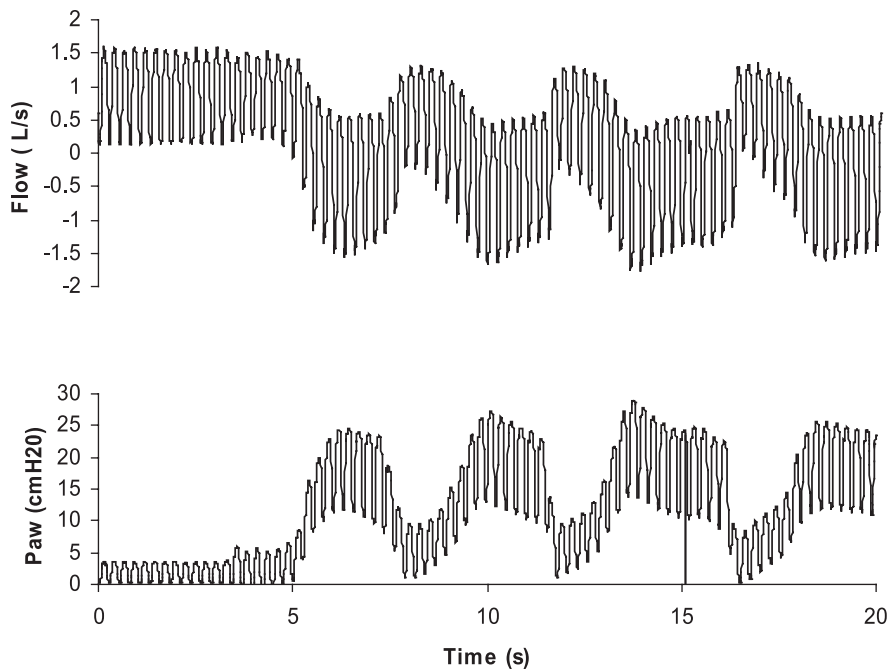


Figure 1. Traces of flow and pressure (P_{aw}) recorded at the mouthpiece when intrapulmonary percussive ventilation (IPV) is applied (*arrow*) to the patient at rates of 225 cycles per minute during spontaneous breathing, immediately after discontinuation of the noninvasive positive pressure ventilation helmet. In the first 4 secs, the mouthpiece is not connected to the patient but only to IPV. The delivered high-flow mini-bursts generate positive increasing pressure with a peak delivery pressure <40 cm H_2O .

distal to partially obstructed airways (29) and by increasing the homogeneity of distribution of perfusion and ventilation (36). As an overall result, dead-space volume is reduced, CO_2 elimination increases, and work of breathing diminishes (36, 37). We tested the efficacy of one session of IPV. For this purpose, physiologic variables were measured before and after a 30-min session of IPV. Table 4 depicts an improvement in all measured variables suggesting that IPV is a useful and safe therapy under the present experimental circumstances.

We did not measure the selected physiologic variables after conventional respiratory physiotherapy in the other group prospectively studied. This can be considered a potential limitation of the study, and the comparison would probably have brought more value to the modifications observed after the first session of IPV. Indeed, our aims were not to compare the responses to the first application of IPV and physiotherapy but to verify the feasibility of IPV during acute exacerbation of COPD and to compare the effects of daily sessions of IPV and physiotherapy during NIV on the clinical events (need of intubation, duration of supported ventila-

tion, length of ICU stay, complications) connected to the time course of the exacerbation of COPD. In line with this approach, the missing measurements for the variables after conventional respiratory physiotherapy do not deprive us of information on the groups.

Antonelli et al. (9, 33) found an excellent tolerance to the helmet (no treatment failure) but reported 36% and 38% failure to facial mask. Under this point of view the helmet was shown to be the best interface between the patient and the ventilator. Our data demonstrated that two patients could not tolerate the helmet because of the stripes, whereas eight control patients were intubated for intolerance to the facial mask. Conversely, IPV treatment (twice a day) was well tolerated in all instances, and adverse effects were not found.

Finally, three patients in the IPV group and four in the Phys group had been previously admitted to the ICU. However, these admissions occurred at least 6 months before the present study was begun. Furthermore, we tested the duration of stay in the ICU for the patients who were in the ICU for the first time versus the three and four aforementioned patients, and no differences were detected.

CONCLUSIONS

In patients with acute exacerbation of COPD, the association of IPV and NPPV with helmet reduced the duration of the artificial ventilation, reduced ICU stay, and improved gas exchange.

ACKNOWLEDGMENT

Dr. W. A. Zin is a researcher of the Brazilian National Council for Scientific and Technological Development (CNPq/MCT), Brazil and a visiting professor at the School of Critical Care, Facoltà di Medicina, Università degli Studi di Trieste, Italy.

REFERENCES

1. Bott J, Carroll MP, Conway JH, et al: Randomized controlled trial of nasal ventilation in acute ventilatory failure due to chronic obstructive airways disease. *Lancet* 1993; 341: 1555-1557
2. Brochard L, Mancebo J, Wysocki M, et al: Non invasive ventilation for acute exacerbation of chronic obstructive pulmonary disease. *N Engl J Med* 1995; 333:817-822
3. Meduri GU, Turner RE, Abou-Shala N, et al: Noninvasive positive pressure ventilation via face mask: First-line intervention in patients with acute hypercapnic and hypoxemic respiratory failure. *Chest* 1996; 109:179-193
4. Hilbert G, Gruson D, Gbikpi-Benissan G, et al: Sequential use of noninvasive pressure support ventilation for acute exacerbation of COPD. *Intensive Care Med* 1997; 23:955-961
5. Peter JV, Moran JL, Phillips-Hughes J, et al: Noninvasive ventilation in acute respiratory failure. A meta-analysis update. *Crit Care Med* 2002; 30:555-562
6. Lightowler JV, Wedzicha JA, Elliott MW, et al: Noninvasive positive pressure ventilation to treat respiratory failure resulting from exacerbation of chronic obstructive pulmonary disease: Cochrane systematic review and meta-analysis. *BMJ* 2003; 326:185-190
7. Plant PK, Owen JL, Elliott MW: Non-invasive ventilation in acute exacerbation of chronic obstructive pulmonary disease: Long term survival and predictors of in-hospital outcome. *Thorax* 2001; 56:708-712
8. International Consensus Conferences in Intensive Care Medicine: Noninvasive positive pressure ventilation in acute respiratory failure. *Am J Respir Crit Care Med* 2001; 163: 283-291
9. Antonelli M, Pennisi MA, Pelosi P, et al: Non-invasive positive pressure ventilation using a helmet in patients with acute exacerbation of chronic obstructive pulmonary disease. *Anesthesiology* 2004; 100:16-24
10. Racca F, Appendini L, Gregoretto C, et al: Effectiveness of mask and helmet interfaces to deliver noninvasive ventilation in a human

model of resistive breathing. *J Appl Physiol* 2005; 99:1262–1271

11. Natale JE, Pfeifle J, Homnick DN: Comparison of intrapulmonary percussive ventilation and chest physiotherapy. *Chest* 1994; 105: 1789–1793
12. Homnick DN, White F, de Castro C: Comparison of effects of an intrapulmonary percussive ventilator to standard aerosol and chest physiotherapy in treatment of cystic fibrosis. *Pediatr Pulmonol* 1995; 20:50–55
13. Toussaint M, De Win H, Steens M, et al: Effect of intrapulmonary percussive ventilation on mucus clearance in Duchenne muscular dystrophy patients: A preliminary report. *Respir Care* 2003; 48:940–947
14. Birnkrant DJ, Pope JF, Levarskij J, et al: Persistent pulmonary consolidation treated with intrapulmonary percussive ventilation: A preliminary report. *Pediatr Pulmonol* 1996; 21:246–249
15. Deakins K, Chatburn RL: A comparison of intrapulmonary percussive ventilation and conventional chest physiotherapy for the treatment of atelectasis in the pediatric patient. *Respir Care* 2002; 47:1162–1167
16. Bellone A, Spagnolatti L, Massobrio M, et al: Short term effect of expiration under positive pressure in patients with acute exacerbation of chronic obstructive pulmonary disease and mild acidosis requiring non-invasive positive pressure ventilation. *Intensive Care Med* 2002; 28:581–585
17. Plant PK, Owen JL, Elliot MW: Early use of non-invasive ventilation in acute exacerbation of chronic obstructive pulmonary disease on general respiratory wards: A multicentre randomised trial. *Lancet* 2000; 335: 1931–1935
18. Brochard L, Harf A, Lorino H, et al: Inspiratory pressure support prevents diaphragmatic fatigue during weaning from mechanical ventilation. *Am Rev Respir Dis* 1989; 139:513–521
19. McCrory DC, Brown C, Gelfand SE, et al: Management of acute exacerbation of COPD: A summary and appraisal of published evidence. *Chest* 2001; 119:1190–1209
20. Anthonisen P, Riis P, Sogaard-Andersen T: The value of lung physiotherapy in the treatment of acute exacerbation in chronic bronchitis. *Acta Med Scand* 1964; 175:715–719
21. Newton DA, Bevans HG: Physiotherapy and intermittent positive-pressure ventilation of chronic bronchitis. *BMJ* 1976; 2:1525–1528
22. Campbell AH, O'Connell JM, Wilson F: The effect of chest physiotherapy upon the FEV1 in chronic bronchitis. *Med J Aust* 1975; 1:33–35
23. Pryor JA: Physiotherapy for airway clearance in adults. *Eur Respir J* 1999; 14:1418–1424
24. Bach JR, Ishikawa J, Kim H: Prevention of pulmonary morbidity for patients with Duchenne muscular dystrophy. *Chest* 1997; 112: 1024–1028
25. Bach JR: Update and perspective on noninvasive respiratory muscle aids. Part 2: The expiratory aids. *Chest* 1994; 105:1538–1544
26. Hess DR: The evidence for secretion clearance techniques. *Respir Care* 2001; 46: 1276–1293
27. McInturff SL, Shaw LI, Hodgkin JE, et al: Intrapulmonary percussive ventilation in the treatment of COPD. *Abstr. Respir Care* 30: 885
28. Fink JB, Mahlmeister MJ: High-frequency oscillation of the airway and chest wall. *Respir Care* 2002; 47:797–807
29. Chang HK: Mechanisms of gas transport during ventilation by high frequency oscillations. *J Appl Physiol* 1984; 56:553–563
30. Drazen JM, Kamm RD, Slutsky AS: High-frequency ventilation. *Physiol Rev* 1984; 64: 505–543
31. Froese AB, Bryan AC: High frequency ventilation. *Am Rev Respir Dis* 1987; 135: 1363–1374
32. Slutsky AS: Mechanisms affecting gas transport during high frequency oscillations. *Crit Care Med* 1984; 12:713–717
33. Antonelli M, Conti G, Pelosi PM, et al: New treatment of acute hypoxemic respiratory failure: Noninvasive pressure support ventilation delivered by helmet—A pilot controlled trial. *Crit Care Med* 2002; 30: 602–608
34. Tomkiewicz RP, Biviji A, King M: Effects of oscillating air flow on the rheological properties and clearability of mucous gel simulants. *Biorheology* 1994; 31:511–520
35. King M, Zidulka A, Philips DM, et al: Tracheal mucus clearance in high-frequency oscillation: Effects of peak flow rate bias. *Eur Respir J* 1990; 3:6–13
36. Eckmann DM, Gavriely N: Chest vibration redistributes intra-airway CO₂ during tracheal insufflation in ventilatory failure. *Crit Care Med* 1996; 24:451–457
37. Gavriely N, Eckmann D, Grotberg JB: Intra-airway gas transport during high-frequency chest vibration with tracheal insufflation in dogs. *J Appl Physiol* 1995; 79:243–250