Active cycle of breathing techniques in non-invasive ventilation for acute hypercapnic respiratory failure

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We hypothesised that applying the active cycle of breathing techniques (ACBT) in patients with acute hypercapnic respiratory failure undergoing non-invasive ventilation would improve patient outcome. Thirty-four patients were randomised so that 17 patients with acute hypercapnic respiratory failure received the ACBT and non-invasive ventilation (ACBT group), and 17 patients received non-invasive ventilation alone (control group). The primary outcome measure was length of time requiring non-invasive ventilation, and secondary outcome measures were change in acute physiology score, change in arterial blood gas values, total duration of non-invasive ventilation, and length of stay in the intensive care unit. Although not significant, there was a greater decrease in arterial carbon dioxide pressure in the ACBT group compared to the control group (-21.41 mmHg *vs* -17.45 mmHg, $p = 0.27$). Total duration of ventilation tended to be shorter in the ACBT group than in the control group (64.9 hours *vs* 84.1 hours, $p = 0.15$). Length of time in need of non-invasive ventilation was significantly lower in the ACBT group than in the control group (5.0 days *vs* 6.7 days, $p = 0.03$). There was no significant difference in length of stay in the intensive care unit between the two groups (8.0 *vs* 9.4 days, $p = 0.31$). The use of ACBT may have positive effects in the treatment of patients with acute hypercapnic respiratory failure, resulting in a shorter length of time requiring non-invasive ventilation. **[Inal-Ince D, Savci S, Topeli A and Hulya Arikan H (2004): Active cycle of breathing techniques in non-invasive ventilation for acute hypercapnic respiratory failure. Australian Journal of Physiotherapy 50: 67-73]**

Key words: Physiotherapy; Acute Respiratory Failure; Intensive Care; Non-invasive Ventilation

Introduction

Respiratory physiotherapy is considered integral to the management of patients in the intensive care unit (ICU). The goals of physiotherapy are to optimise oxygen transport, improve ventilation-perfusion matching, increase lung volumes, reduce work of breathing, and enhance mucociliary clearance (Ciesla 1996, Stiller 2000). Most ICU studies have investigated the short-term effects of multimodality physiotherapy on pulmonary function in intubated patients receiving mechanical ventilation (Mackenzie et al 1980, Mackenzie and Shin 1985, Stiller et al 1990).

As new therapeutic modalities emerge to treat ICU patients, there is a need to investigate the effect of respiratory physiotherapy techniques in patients receiving these applications. One of these new approaches is non-invasive ventilation (NIV), which has been increasingly and successfully used in the treatment of acute respiratory failure (Anton et al 2000, Brochard et al 1995, Carlucci et al 2001, Celikel et al 1998). A number of techniques including positioning, flutter, positive expiratory pressure (PEP) therapy, and the active cycle of breathing techniques (ACBT) have been suggested for patients undergoing NIV (Bott et al 2001). In a few NIV studies respiratory physiotherapy was described as a part of standard medical treatment (Anton et al 2000, Bott et al 1993, Conway et al 1993) but no information was given about the characteristics of patients receiving physiotherapy, or the techniques applied to them. To our knowledge, there is only one controlled study investigating the effects of a respiratory physiotherapy technique in patients with acute respiratory failure receiving NIV. Bellone et al (2002) showed favourable results with the use of a PEP mask in patients with acute exacerbation of chronic obstructive pulmonary disease.

ACBT is one of the techniques that can be used in patients receiving NIV. It requires active participation of the patients but does not require a device such as a PEP mask. It can be adapted easily to patients with different disease states (Pryor and Webber 2002). It is an effective treatment in improving pulmonary function (Savci et al 2000, Verboon et al 1986, Webber et al 1986) and airway clearance (Pryor et al 1979, Wilson et al 1995). It has been evaluated in stable patients with cystic fibrosis (Pryor et al 1979, Verboon et al 1986, Webber et al 1986) and chronic obstructive pulmonary disease (Savci et al 2000). However, there is only one case report related to its use in ICU showing that the ACBT prevented the need for intubation in a patient with acute respiratory failure (Wong 2000). Therefore, we performed a prospective randomised controlled study to test the hypothesis that applying the ACBT in patients with acute hypercapnic respiratory failure receiving NIV would improve patient outcome. In our study, the primary outcome measure was length of time in need of NIV, and secondary outcome measures were changes in acute physiology score and arterial blood gas values, total duration of NIV, need for intubation, mortality, and length of stay in the ICU.

Method

Subjects The study was conducted in a 9-bed medical ICU of a university hospital, for an 18-month period between November 2000 and May 2002. The study protocol was approved by the Institute of Health Sciences. All patients with acute hypercapnic respiratory failure in need of NIV, as judged by the attending physician, were included in the study. Acute hypercapnic respiratory failure was defined as an arterial blood pH < 7.35 and an arterial carbon dioxide pressure ($PaCO_2$) > 45 mmHg (Grippi 1998). Exclusion criteria were a need for immediate life-saving endotracheal intubation, intubation prior to admission to the ICU, facial

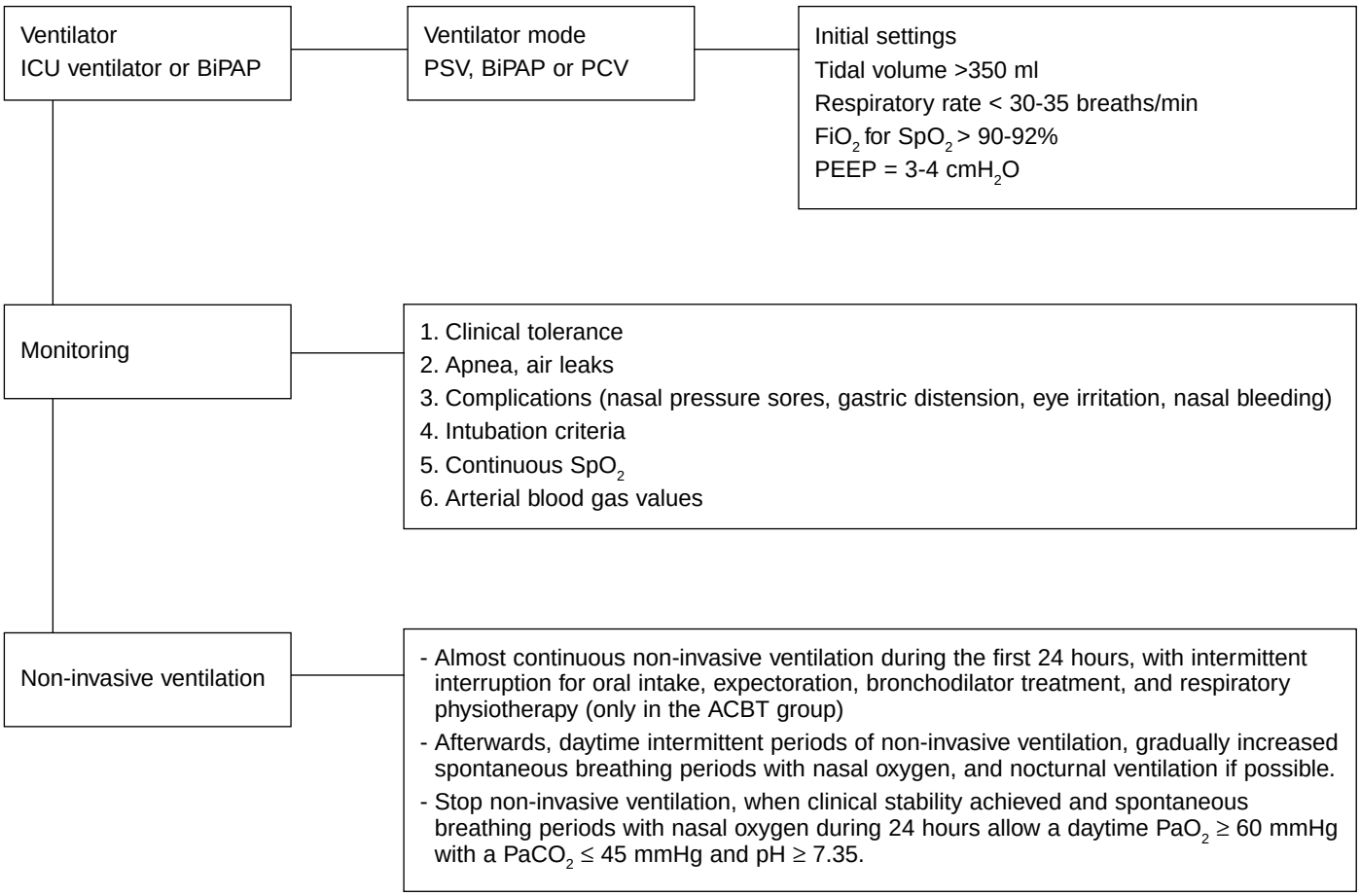

Figure 1. Clinical application of non-invasive ventilation. ICU = intensive care unit, PSV = pressure support ventilation, PCV = pressure control ventilation, FiO_2 = fraction of inspired oxygen, SpO_2 = oxygen saturation, PEEP = positive end–expiratory pressure, ACBT = active cycle of breathing techniques, PaO_2 = arterial oxygen pressure, $PaCO_2$ = arterial carbon dioxide pressure.

deformity, haemodynamic instability, inability to protect the airway, extreme agitation, and unco-operativeness. Eligible patients were allocated randomly, using file numbers, to receive either ACBT and NIV (ACBT group) or NIV alone (control group) by the physiotherapy team. The NIV application, all other patient care, and measurements were provided by the primary ICU team. The attending physician took the decisions related to NIV management, and physiotherapists were involved only the decisions related to the application of the ACBT.

Measurements Patient demographics, home oxygen use, co-morbid illnesses, and cause of respiratory failure were recorded. Lung function data were noted if these had been measured while the patient was clinically stable within the preceding year. Body mass index was calculated. Pre-morbid activities of daily living were recorded according to the information taken from patients or relatives, and scored on a 5-point scale from 0 = working, to 4 = bed- or chair-bound (Menzies et al 1989).

Heart rate, blood pressure, respiratory rate, arterial blood gas values, chest radiographs, white blood cell and platelet counts, haemoglobin and serum albumin level, and Glasgow Coma Score were recorded on admission. The Acute

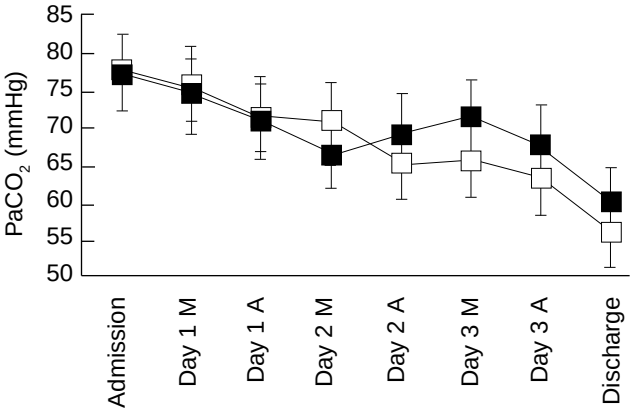

Figure 2. Changes in arterial carbon dioxide pressure ($PaCO_2$) from admission to discharge in the active cycle of breathing techniques (ACBT) and control groups. □ = ACBT group, ■ = control group, M = morning, A = afternoon. Data are means and standard deviations.

Table 1. Characteristics and admission findings of the patients.

	ACBT (*n* = 17)	Control (*n* = 17)	*p* value
Age (years)	65 ± 8	65 ± 13	0.59
Sex Male:Female	8:9	4:13	0.14
Body mass index (kg/m^2)	30 ± 8	26 ± 7	0.33
Smoking (pack-years)	31 ± 32	18 ± 24	0.24
APACHE II score	18.3 ± 3.6	19.3 ± 4.2	0.52
Acute physiology score	9.3 ± 2.8	10.3 ± 3.4	0.58
Heart rate (beats/min)	105 ± 17	98 ± 19	0.30
Mean arterial pressure (mmHg)	93 ± 14	92 ± 16	0.97
Respiratory rate (breaths/min)	31 ± 3	30 ± 6	0.64
$PaCO_2$ (mmHg)	77.7 ± 11.1	77.3 ± 13.5	0.88
pH	7.27 ± 0.05	7.27 ± 0.05	0.63
PaO_2/FiO_2 ratio	273 ± 155	259 ± 104	0.77
Cor pulmonale	5 (29%)	3 (18%)	0.34
Co-morbidities	16 (94%)	15 (88%)	0.50
Home oxygen therapy	3 (18%)	3 (18%)	1.00
ADL prior to admission	1.8 ± 0.8	1.8 ± 0.8	1.00

Data are means ± SD or *n* (%). ACBT = active cycle of breathing techniques, APACHE = Acute Physiology and Chronic Health Evaluation, $PaCO_2$ = arterial carbon dioxide pressure, PaO_2/FiO_2 = ratio of arterial oxygen pressure to fraction of inspired oxygen, ADL = activities of daily living.

Table 2. Causes of respiratory failure.

	ACBT (*n* = 17)	Control (*n* = 17)
COPD, acute exacerbation	5 (29%)	11 (65%)
COPD, pneumonia	3 (18%)	3 (18%)
COPD, bronchiectasis, pneumonia	3 (18%)	2 (12%)
Previous pneumonectomy, pneumonia	2 (12%)	0
Bronchial asthma, pneumonia	1 (6%)	1 (6%)
Bronchiectasis, ankylosing spondilitis	1 (6%)	0
Interstitial lung disease	1 (6%)	0
Pneumonia	1 (6%)	0

Data are *n* (%). ACBT = active cycle of breathing techniques, COPD = chronic obstructive pulmonary disease.

Physiology and Chronic Health Evaluation II (APACHE II) score was calculated in the first 24 hours of admission (Knaus et al 1985). The acute physiology score in the last 24 hours of ICU stay was also calculated (Knaus et al 1985). Morning (0800) and afternoon (1600) arterial blood gas values, and ventilator parameters were noted from the ICU flow sheet. Total duration of NIV (the sum of hours in which patient was on NIV), length of time in need of NIV (the total length of time in days until the patient was not on NIV during the day at all), length of ICU stay, need for intubation, and mortality were recorded. In the ACBT group heart rate, blood pressure, respiratory rate, oxygen saturation (SpO_2) before and after the application were recorded. Change in fraction of inspired oxygen (FiO_2) during the application, and the duration of treatment for a single session were also recorded.

Non-invasive ventilation The NIV was applied by BiPAP[(a)] or by ICU ventilator[(b)] with a commercially available full face mask (Meduri and Spencer 2001, Mehta and Hill 2001). Initial ventilatory settings were adjusted according to patient tolerance, clinical monitoring, and arterial blood gas measurements. First line ventilatory mode was pressure support ventilation with external positive end-expiratory pressure, or BiPAP. In the case of air leak or apnoea, pressure control ventilation was used as a mode of choice (Meduri and Spencer 2001). Ventilatory support was continued according to the strategy described in Figure 1 (Anton et al 2000, Celikel et al 1998, Mehta and Hill 2001, Meduri and Spencer 2001). The patients were discharged from the ICU if they were clinically stable 24–72 hours after the completion of the NIV. Failure of NIV was defined as the need for intubation or death causally related to NIV. The criteria for intubation were respiratory arrest, haemodynamic instability and/or severe cardiac arrhythmias, severe agitation, and altered mental status.

Active cycle of breathing techniques Respiratory physiotherapy was applied by using the ACBT (Pryor and Webber 2002) to all patients by the same respiratory physiotherapist who had 10 years experience in the clinical application of the technique. The ACBT consisted of 4–6 breathing control breaths, 3–4 thoracic expansion exercises, and the forced expiration technique including 4–6 breathing control breaths combined with 2–3 huffs (Pryor and Webber 2002). If there were copious or viscous secretions, ineffective cough or huff, coarse crackles on auscultation, then chest percussion and shaking were combined with thoracic expansion exercises (Bott et al 2001, Pryor and Webber 2002).

The ACBT was applied once per day during the ICU stay. Patients were not instructed nor encourged to perform the ACBT independently of the physiotherapist. Ventilatory assistance was not used, and oxygen treatment was continued during the ACBT application. Duration of the ACBT in a single session was determined according to affected side(s) of the lung and patient tolerance, and was kept between 15 and

Table 3. Total duration and length of time requiring non-invasive ventilation, and length of stay in the intensive care unit.

	ACBT (n = 17)	Control (n = 17)	Difference (95% CI)	p value
Total duration of NIV (hours)	64.9 ± 29.7	84.1 ± 36.6	19.3 (1.2 to 37.4)	0.15
Length of time requiring NIV (days)	5.0 ± 2.5	6.7 ± 2.6	1.7 (-0.3 to 3.8)	0.03
Length of ICU stay (days)	8.0 ± 3.9	9.4 ± 4.4	1.3 (-0.5 to 3.1)	0.31

Data are means ± SD. ACBT = active cycle of breathing techniques, NIV = non-invasive ventilation, ICU = intensive care unit.

30 minutes per session. The patient was positioned in high side lying according to the affected side of the lung. If the patient did not tolerate this position (if signs of respiratory distress developed), high sitting was preferred. The forward lean sitting position was used when posterior aspects of the lung were involved (Bott et al 2001, Pryor and Webber 2002). Because the active participation of the patient was required, attention was given to ensure that the patient was not exhausted and had a comfortable breathing pattern before the application of treatment.

Data analysis The primary outcome measure was length of time in need of NIV, which was the total length of time until the patient was not on NIV during the day at all. Secondary outcome measures were change in acute physiology score, change in arterial blood gas values, total duration of NIV, need for intubation, mortality, and length of stay in the ICU. A power analysis was performed prior to the study, and a sample size of 32 (16 patients in each group) was found to be sufficient, with an 80% power for detecting a minimum difference of one day (SD = 1 day) in the length of time in need of NIV, the primary outcome variable.

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 10.0. Categorical variables were compared using Chi-square or Fisher's exact test, as appropriate. Wilcoxon signed rank test was used for within-group comparisons, and Mann-Whitney U test for between-group comparisons of numerical variables. Friedman's test was used to analyse duration of the ACBT in sessions on the first, second, and last days of ICU stay (Green et al 2000) since minimum ICU stay was found to be 3.2 days in our study. Repeated measures of analysis of variance was performed to analyse arterial blood gas values, daily duration of NIV, pressure support, and tidal volume between the groups (Green et al 2000, Tabachnick and Fidell 1996). Statistical significance was defined as a value of $p < 0.05$.

Results

Thirty-five patients were found to be eligible to the study. None of the patients had prior experience of the ACBT, and no patient was excluded from the study due to lack of active participation. One patient from the control group refused treatment 1.5 days after admission, and was discharged from the ICU at his request. Of the remaining 34 patients, 17 were in the ACBT group and 17 were in the control group. The two groups were similar with regard to age, APACHE II score, arterial blood gas values and other characteristics ($p > 0.05$, Table 1). There was no significant difference in the distribution of causes of respiratory failure between the groups ($p = 0.25$, Table 2). The use of medical treatment (bronchodilators, antibiotics, and corticosteroids) did not differ significantly between the two groups ($p > 0.05$).

Neither the kind of ventilator nor mode of ventilation used differed significantly between the two groups ($p > 0.05$). Similarly, level of support and tidal volume supplied throughout the NIV did not differ significantly between the groups ($p > 0.05$). There was no significant difference in the daily duration of NIV on the first (16.6 ± 3.6 hours for ACBT group *vs* 16.2 ± 3.9 hours for control group), second (11.1± 5.2 hours for ACBT group *vs* 14.2 ± 4.9 hours for control group) or third (13.7 ± 4.1 hours for ACBT group *vs* 12.3 ± 5.3 hours for control group) days of the ICU stay ($p = 0.15$).

The mean acute physiology score decreased significantly from baseline by -1.9 (95% CI -3.6 to -0.2, $p = 0.03$) in the ACBT group, and by -2.7 (95% CI -5.5 to 0.2, $p = 0.03$) in the control group at ICU discharge. Similarly, arterial pH increased significantly to normal values from baseline by a mean of 0.11 (95% CI 0.08 to 0.14, $p < 0.001$) in the ACBT group, and by a mean of 0.11 (95% CI 0.08 to 0.15, $p < 0.001$) in the control group at ICU discharge. However, changes in acute physiological score ($p = 0.68$) and arterial pH ($p = 0.76$) were not statistically significant between the groups. The $PaCO_2$ decreased significantly from admission to discharge by a mean of -21.4 (95% CI -28.2 to -14.6) mmHg in the ACBT group ($p < 0.001$), and by a mean of -17.5 (95% CI -24.9 to -10.0) mmHg in the control group ($p = 0.001$). As seen in Figure 2, the reduction of $PaCO_2$ was larger in the ACBT group than in the control group but there was no significant difference between the two groups ($p = 0.27$).

Although total duration of NIV and length of ICU stay were shorter in the ACBT group than in the control group, neither variable was statistically significant ($p > 0.05$, Table 3). The mean length of time NIV was required for the ACBT group was significantly shorter than for the control group ($p = 0.03$, Table 3). One patient from ACBT group and one patient from the control group required endotracheal intubation and invasive mechanical ventilation 6.5 and five days after the beginning of the NIV, respectively. Nasal pressure sores were observed in seven patients from the ACBT group and in six patients from the control group. Other adverse events were eye irritation in two patients from the ACBT group and one patient from control group, and nose bleeding in one patient from the control group. Patients in both groups were discharged from the ICU after a successful treatment, and no patient died during the study period.

There was no significant difference in the duration of ACBT during the ICU stay ($p = 0.36$, Table 4). No significant differences were found in heart rate, blood pressure, or respiratory rate as an acute response to the application of ACBT ($p > 0.05$, Table 4). On the last day of the ICU stay, the

Table 4. Acute responses to the active cycle of breathing techniques on Day 1, Day 2, and the last day of the stay in the intensive care unit.

	Day 1		Day 2		Last day	
	Pre-ACBT	Post-ACBT	Pre-ACBT	Post-ACBT	Pre-ACBT	Post-ACBT
Heart rate (beats/min)	99.4 ± 17.0	100.0 ± 19.6	96.7 ± 17.5	96.2 ± 18.9	93.9 ± 19.0	93.4 ± 19.0
Systolic blood pressure (mmHg)	124.8 ± 19.5	126.7 ± 19.3	129.3 ± 19.4	128.7 ± 19.1	124.2 ± 19.0	128.0 ± 18.9
Diastolic blood pressure (mmHg)	69.4 ± 11.3	68.9 ± 13.5	69.9 ± 10.9	67.8 ± 9.1	73.8 ± 10.3	69.9 ± 14.2
Respiratory rate (breaths/min)	24.8 ± 5.6	24.3 ± 6.4	25.2 ± 6.2	26.9 ± 6.8	23.6 ± 4.3	24.8 ± 4.6
Oxygen saturation (%)	92.0 ± 5.3	91.5 ± 5.4	93.0 ± 3.4	92.2 ± 4.0	91.2 ± 4.1	93.8 ± 3.7*
Fraction of inspired oxygen (%)	31.4 ± 9.5	31.8 ± 9.9	33.7 ± 10.0	33.7 ± 10.0	25.4 ± 3.6	25.4 ± 3.6
Duration of ACBT (min)	18.8 ± 8.4		20.9 ± 7.3		18.2 ± 6.6	

Data are means ± SD. ACBT = active cycle of breathing techniques, *Significant difference between Pre-ACBT and Post-ACBT (p = 0.006).

mean SpO_2 increased significantly from baseline by 2.6% (95% CI 0.7 to 4.5%) as an acute response to the ACBT treatment (p = 0.006, Table 4) despite a non-significant change in FiO_2 during the treatment ($p > 0.05$, Table 4).

Discussion

In this study, we showed that inclusion of the ACBT in NIV application to patients with acute hypercapnic respiratory failure decreased the length of time NIV was needed by almost two days. In addition, decrease in $PaCO_2$ was greater, the mean ICU stay was 1.3 days less, and the mean duration of NIV was 19 hours shorter in patients receiving both the ACBT and NIV. There were no acute adverse responses to the ACBT treatment in terms of SpO_2, heart rate, blood pressure, and respiratory rate. These findings reveal that the inclusion of the ACBT in the management of patients receiving NIV could accelerate recovery from acute hypercapnic respiratory failure without any detrimental effects.

Some studies have suggested undesirable acute effects of conventional chest physiotherapy on pulmonary function in patients with acute exacerbations of chronic bronchitis. Campbell et al (1975) and Wollmer et al (1985) demonstrated a decrease in forced expiratory volume in one second (FEV_1) as an acute response to head-down positioning combined with chest percussion in patients with acute exacerbations of chronic bronchitis. Although it is a reliable measure of respiratory function, use of FEV_1 as an outcome measure in the acute setting has not been recommended because of its insensitivity to changes in clinical condition (Bach et al 2001). In another study, Connors et al (1980) showed an acute reduction in arterial oxygenation with the same treatment in 22 acutely ill patients, including six patients who were intubated and mechanically ventilated. Despite this finding, Pryor et al (1990) demonstrated no reduction in arterial oxygenation during ACBT where chest percussion is combined with thoracic expansion exercises, and breathing control are interspersed during the cycle in patients with acute exacerbation of cystic fibrosis. In addition, Wong (2000) showed that use of the ACBT improved arterial oxygenation with resolution of infiltrates in a patient with acute respiratory failure. Similarly, we showed that the ACBT did not cause any acute detrimental effects in patients with acute hypercapnic respiratory failure receiving NIV.

Although various respiratory physiotherapy techniques have been proposed, to our knowledge only the effect of the PEP mask in patients with acute respiratory failure receiving NIV has been investigated in a controlled study. Bellone et al (2002) investigated the supplementary effect of providing PEP in addition to assisted cough in patients receiving NIV due to acute exacerbation of chronic obstructive pulmonary disease. They showed that a combination of PEP mask and assisted cough decreased NIV duration, and increased sputum production as compared to assisted cough alone. Length of ICU stay did not differ significantly between the groups in their study.

This study investigated the effects of the use of ACBT in patients receiving NIV due to acute hypercapnic respiratory failure. Although the investigation of the mechanisms of the ACBT in patients receiving NIV was beyond the scope of our study, the individual effects of three breathing manoeuvers in the ACBT, most probably enhanced mucociliary clearance, could be responsible for the findings of this study. Weight or volume of sputum expectorated is one of the measures that can be used to determine airway clearance. We did not use this measure because it is not a reliable indicator of the effectiveness of airway clearance (Rossman et al 1982). Hasani et al (1994) showed that unproductive forced expiration technique improved mucociliary clearance.

A lack of significant difference in arterial blood gas tensions between the groups could be related to the frequency of the ACBT application used in this study. The number of physiotherapists in the ICU determines the frequency of treatment (Ntoumenopoulos et al. 1991). In our country, like in most European countries, physiotherapy services could not be given continuously for 24 hours per day (Norrenberg 2000). Although power analysis was performed to determine the number of patients for the primary outcome variable, the length of time requiring NIV, the sample size might still not be sufficient to detect significant differences in arterial blood gas values. Furthermore, the sample size was similar to that used in other single centre controlled studies (Anton et al 2000, Celikel et al 1998). Large samples are difficult to obtain since NIV can be applied only to certain patients (Meduri and Spencer 2001, Mehta and Hill 2001), and only 30–35% of ICU patients are suitable for NIV treatment (Brochard et al 1995, Carlucci et al 2001).

Some limitations of this study should be considered when interpreting the results. First, the blinding of group

assignment by the primary ICU team was not possible, and this may have introduced a bias. However, an independent physician took the decisions related to the application of NIV, and the physiotherapist, who performed the ACBT, was not involved in the decision-making process related to NIV outcome (total duration and length of time in NIV, need for intubation, and length of stay in the ICU). Second, a relatively higher percentage of the patients with acute exacerbation of chronic obstructive pulmonary disease in the control group may have resulted in poorly matched groups. However, there was no significant difference in the distribution of causes of respiratory failure between the groups, and group equivalence in our study was checked by the severity of illness since the degree of acidosis and APACHE II are the factors determining the success of NIV (Keenan et al 2003, Liesching et al 2003, Lightowler et al 2003, Plant and Elliot 2003). Moreover, the inclusion of patients with a variety of aetiologies for their acute hypercapnic respiratory failure could reflect common respiratory physiotherapy practice in the acute care setting.

Conclusion

The results of this study provide evidence that the use of ACBT in patients with acute hypercapnic respiratory failure is safe, and it could shorten the length of time required for NIV. Therefore, it may have positive effects on the management of these patients. Further studies are needed to show the effects of application of ACBT in increased frequency on arterial blood gases in a larger sample size. In addition, other respiratory physiotherapy techniques besides PEP mask and ACBT should be investigated in patients with acute hypercapnic respiratory failure receiving NIV.

Footnotes [(a)]BiPAP (Respironics Inc, Murrysville, USA). [(b)] ICU ventilator (Model Servo 300, Siemens, Sweden).

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