Average volume-assured pressure support ventilation mode in the management of acute hypercapnic respiratory failure
Ashraf Zin El-Abdin, Lamiaa H. Shaaban, Shereen Farghaly, Sarah Hashim

Background Although average volume-assured pressure support (AVAPS) mode has been studied in chronic respiratory failure, studies evaluating its efficacy in acute hypercapnic respiratory failure (AHRF) are limited.

Objective The aim of this study was to investigate the benefits of spontaneous timed AVAPS (ST/AVAPS) mode in delivering noninvasive ventilation (NIV) for patients with AHRF compared with the conventional ST/BiPAP (ResMED, San Diego, California, USA) mode.

Introduction Mechanical ventilation is considered an effective management for patients with acute respiratory failure (RF). However, it is associated with many hazards to the patient when the tube is in place or after its removal. In recent years, noninvasive ventilation (NIV) has been developed to improve ventilation and oxygenation without the need for an endotracheal intubation and has proved its effectiveness in the management of RF [1–3].

BiPAP (ResMED, San Diego, California, USA) therapy as a type of pressure-limited noninvasive positive pressure ventilation (NPPV) mode has gained interest for its variability of administered pressure between inspiration and expiration. That variable pressure can decrease the amount of pressure against which the patient exhales and thus decreases excessive respiratory effort during the expiratory cycle. Moreover, it provides less peak inspiratory pressure [4]. On the other hand, volume-limited NPPV prevents fluctuation of tidal volume (VT) in the presence of changes in patient effort, chest wall compliance, or airway resistance [5]. Recently, hybrid modes that combine the benefit of pressure-targeted and volume-targeted ventilation have been developed in the treatment of acute hypercapnic respiratory failure (AHRF). Average volume-assured pressure support (AVAPS) is one of those newly developed modes [6]. AVAPS is a mode of NIV that estimates the patient’s VT over several breathes and calculates the variations in inspiratory positive airway pressure (IPAP) needed to achieve the patient’s target VT aiming for patient safety and comfort [7]. Although this mode has been studied in chronic RF, studies evaluating its efficacy in AHRF are limited.
and obstructive sleep apnea), was made clinically, radiologically, and based on the criteria of diagnosis of these disorders [9–11]. The reasons for ARF were evaluated and recorded as acute exacerbation of COPD [9] or obesity hypoventilation syndrome [10], pneumonia [12], acute heart failure [13], or pulmonary embolism [14]. Patients with pH more than 7.15, disturbed conscious level attributed to causes other than RF (hepatic or uremic encephalopathy and neurological diseases), and Glasgow Coma Scale (GCS) less than 8 or those who had absolute or relative contraindications to NIV were excluded from the study [8].

Noninvasive device
A NIV, ResMED (S9 VPAP ST; ResMED, San Diego, California, USA), was used in this study. The device consists of two major parts, the S9 device unit and the HSi (ResMED, San Diego, California, USA) humidifier unit. The S9 device unit comprises the compressor that compresses room air into pressurized air to deliver positive airway pressure. The HSi humidifier unit comprises the humidifier into which distilled sterile water is poured and filling is guided by a scale of three grades minimum, medium, and maximum. On the inner side of S9 device unit, an air outlet is present, thus delivering humidified air to the patient through the air tube connected to the mask.

Initiation of noninvasive ventilation
The patients were gently placed in the sitting position and simply were explained the technique of the device. Patients were then fitted with oronasal mask ultamirage II mask (ResMed) connected to the device, which was chosen on individual basis. Patients were randomized to receive NIV using either BiPAP-ST mode (group I) or BiPAP-ST/AVAPS (group II).

Ventilatory settings
Expiratory positive airway pressure (EPAP) was adjusted at 3 cm H2O. In patients with known obstructive sleep apnea, EPAP was initially adjusted at 4–5 cm H2O. IPAP was adjusted at 15 cm H2O (20 cm H2O if pH from 7.15–7.25) and then up titrate IPAP to 20–30 to achieve adequate thoracic and abdominal effort and slow RR. Backup rate was set at 16–20 rate/min and inspiratory–expiratory (I : E) ratio at 1 : 2 or 1 : 3 in COPD patients, whereas in other disorders it was adjusted at 1 : 1. Inspiratory time was set at 0.8–1.2 s in COPD patients, whereas in other disorders it was adjusted at 1.2–1.5 s [8]. Parameters for BiPAP-ST/AVAPS mode were adjusted similar to the conventional mode besides including a setting of patient’s height, target VT (6–8 ml/kg of ideal body weight/min in COPD patients and 6 ml/kg ideal body weight/min in other disorders), and minimum and maximum pressure support to provide the required IPAP and EPAP ranges.

Severity of illness assessment
Severity of illness on admission was assessed using the Acute Physiology And Chronic Health Evaluation II [15], the Modified Sequential Organ Failure Assessment Score [16], and the GCS was applied for evaluating the patient’s conscious level [18]. Oxygen was administered through the mask to maintain oxygen saturation from 88 to 92%. Standard medical treatments including inhalational bronchodilators, intravenous corticosteroids, xanthenes, antibiotics, diuretics, or vasopressors were given in addition to NIPPV. Exhaled VT, respiratory rate (RR), heart rate, arterial blood pressure, and arterial blood gas (ABG) were recorded before initiation of NIV and at 1, 12, 48, and 72 h following therapy. Moreover, length of hospital stay (started from the first day of use of NIV until discharge from hospital) and duration of NIV use until obtaining the recommended outcome were recorded.

Defining outcome
Successful therapy was considered when the objective criteria showed a decrease of at least 20% in RR compared with spontaneous breathing, an improvement in ABGs with pH more than 7.35, a decrease in PaCO2 of at least 15% compared with spontaneous breathing while maintaining a SaO2 (with or without oxygen) 88–92% or when the subjective criteria showed improvement in the patient as regards both dyspnea and comfort despite persistent respiratory acidosis [i.e. the inability to obtain a clinically significant decrease in PaCO2 of ≥15% (compared with the initial PaCO2 value under spontaneous breathing) or increase in pH>7.30 after 2 h of therapy] [19].

NIV failure was considered when one major criterion was present at any time, or when two minor criteria persisted after 6 h of NIV. The major criteria included respiratory arrest, respiratory pauses or bradycardia (<50 breath/min) with loss of consciousness, hypotension with systolic arterial blood pressure below 70 mmHg, and refractory hypoxemia with inability to maintain a SaO2 more than 90% despite high FiO2 more than 60%. The minor criteria included tachypnea over 35 breath/min or an increase in the RR compared with its value at admission, pH less than 7.30 and decreased compared with its initial value or a decrease in conscious level compared with its initial value [20].
Statistical analysis

Statistical package for the social sciences (SPSS), version 20 (produced by IBM SPSS statistics for Windows, version 20; IBM Corp., Armonk, New York, USA) software was used for analysis of results. Using tests of normality (the Shapiro–Wilk and Kolmogorov–Smirnov tests), data of duration of hospitalization and duration of NIV were detected to be nonparametric. They were presented in median and interquartile range and analyzed using the Mann–Whitney U-test for comparison between the two study groups. Other results in this study were presented as mean±SD or number and percentage. The qualitative data were compared between the two groups using the $\chi^2$-test and the quantitative data were compared using Student’s $t$-test. Changes in clinical and gasometrical parameters over time among the two groups were analyzed using the one-way analysis of variance test. $P$-value less than 0.05 was considered significant.

Results

A total of 60 patients were included in this study. After randomization, 30 patients were enrolled in group I (ST mode) and 30 patients in group II (ST/AVAPS mode). The two groups were comparable as regards the age, sex, and BMI ($P>0.05$). There were also no significant differences in the underlying cause of RF and cause of admission between the two groups ($P>0.05$) (Table 1). The baseline clinical and gasometrical data as well as disease severity assessment scores (Acute Physiology And Chronic Health Evaluation II, Simplified Acute Physiologic Score II, Modified Sequential Organ Failure Assessment Score) were comparable in both groups (Table 2).

Table 1  Demographic data of the study group (n=60)

| Variables                        | Group I (n=30) | Group II (n=30) | P-value |
|----------------------------------|----------------|----------------|---------|
| Age (years)                      | 56.7±9.8       | 56.1±10.7      | 0.812   |
| Sex                              |                |                |         |
| Male                             | 21 (70)        | 20 (66.7)      | 0.876   |
| Female                           | 9 (30)         | 10 (33.3)      | 0.817   |
| BMI (kg/m²)                      | 31.3±3.7       | 29.4±9.2       | 0.366   |
| Underlying cause of RF           |                |                |         |
| COPD                             | 15 (50)        | 16 (53.3)      | 0.857   |
| Overlap syndrome                 | 10 (33.3)      | 10 (33.3)      | 1.000   |
| OHS                              | 5 (16.7)       | 4 (13.3)       | 0.848   |
| Cause of admission               |                |                |         |
| Infection exacerbation           | 26 (86.7)      | 28 (93.3)      | 0.785   |
| Heart failure                    | 3 (10)         | 2 (6.7)        | 0.655   |
| Pulmonary embolism               | 1 (3.3)        | 0 (0)          | 0.675   |
| Disease severity scores          |                |                |         |
| APACHE II Score                  | 11±3.3         | 10.4±3.6       | 0.503   |
| SAPS II                          | 28.6±9.2       | 25.7±7.6       | 0.194   |
| M SOFA Score                     | 3.3±1.6        | 3.4±1.4        | 0.932   |

Data are presented as frequency [n(%)] or mean±SD. APACHE II, Acute Physiology And Chronic Health Evaluation II; COPD: chronic obstructive pulmonary disease, overlap; COPD and obstructive sleep apnea; M SOFA, Modified Sequential Organ Failure Assessment; OHS, obesity hypoventilation syndrome; RF, respiratory failure; SAPS II, Simplified Acute Physiologic Score II.

Table 2  Baseline clinical and gasometric parameters of the study groups (n=60)

| Variables             | Group I (n=30) (mean±SD) | Group II (n=30) (mean±SD) | P-value |
|-----------------------|--------------------------|---------------------------|---------|
| Clinical              |                          |                           |         |
| GCS                   | 14.47±0.68               | 14.67±0.66                | 0.253   |
| RR (breath/min)       | 28.23±7.06               | 26.03±7.22                | 0.238   |
| HR (rate/min)         | 127.3±14.1               | 122±15.6                  | 0.170   |
| SBP (mmHg)            | 80.7±8.3                 | 77±8.8                    | 0.100   |
| DBP (mmHg)            | 77.6±6.9                 | 76.7±8.9                  | 0.132   |
| ABG                   |                          |                           |         |
| pH                    | 7.32±0.08                | 7.31±0.08                 | 0.606   |
| PaCO₂                 | 75.6±17.46               | 74.1±16.8                 | 0.741   |
| PaO₂                  | 65.53±14.77              | 64.1±15.79                | 0.718   |
| SaO₂                  | 88.9±7.3                 | 84.23±17.51               | 0.183   |

ABG, arterial blood gas; DBP, diastolic blood pressure; GCS, Glasgow Coma Scale; HR, heart rate; PaCO₂, partial arterial carbon dioxide tension; PaO₂, partial arterial oxygen tension; RR, respiratory rate; SaO₂, arterial oxygen saturation; SBP, systolic blood pressure.
We tackled the progress of the patients clinically and using repeated ABG analysis at 1, 12, 48, and 72 h. At 1 h, there was no significant change in GCS, RR, PH, or PaCO₂ in either groups; however, a significant improvement was observed in PaO₂ in both groups I and II and in oxygen saturation in group II (P=0.007) (Table 3). At 12 h, a significant improvement was observed in GCS (15±0 vs. 14.67±0.66, P=0.010), RR (22.7±4.21 vs. 26.03±7.22, P=0.033), and pH (7.37±0.06 vs. 7.31±0.08, P=0.001) with a sustained improvement in PaO₂ and SaO₂ in group II. Meanwhile, in group I, only RR showed a significant improvement at that time (24.17±3.34 vs. 28.23±7.06 P=0.006). Moreover, group I could not maintain the previously detected improvement in oxygen tension with further decrease in oxygen tension at 12 h (Table 4). At 48 h, (Table 5) there was a significant improvement in GCS, RR, pH, PaCO₂, and SaO₂ in group I. In group II, a significant improvement in PaCO₂ started to appear, along with maintenance of the previously acquired improvement in other parameters. At 72 h of follow-up, maintenance of improvement in the monitored parameters continued in both groups (Table 6).

Figure 1 demonstrates exhaled VT over 72 h in both study groups in which we observed fluctuation in VT in group I. Figure 2 shows the estimated outcome for both groups. In group I, the number of successful cases was

---

**Table 3 Changes in Glasgow Coma Scale, respiratory rate, and arterial blood gases at 1 h**

|                     | Group I (n=30) (mean±SD) | Group II (n=30) (mean±SD) |
|---------------------|--------------------------|----------------------------|
|                     | At admission             | At 1 h                     | P-value | At admission             | At 1 h                     | P-value |
| Clinical            |                          |                            |         |                          |                            |         |
| GCS                 | 14.47±0.68               | 14.63±0.67                 | 0.343   | 14.67±0.66               | 14.87±0.35                 | 0.149   |
| RR (breath/min)     | 28.23±7.06               | 26.8±6.04                  | 0.402   | 26.03±7.22               | 24.43±4.14                 | 0.297   |
| ABG                 |                          |                            |         |                          |                            |         |
| pH                  | 7.32±0.08                | 7.34±0.08                  | 0.319   | 7.31±0.08                | 7.35±0.09                  | 0.709   |
| PaCO₂               | 75.6±17.46               | 74.3±15.14                 | 0.600   | 74.13±16.8               | 69.87±16.24                | 0.321   |
| PaO₂                | 65.53±14.77              | 75.9±17.94                 | 0.018*  | 64.1±15.79               | 75.87±21.93                | 0.020*  |
| SaO₂                | 88.9±7.3                 | 91.8±8.53                  | 0.153   | 84.23±17.51              | 93.6±6.22                  | 0.007*  |

ABG, arterial blood gas; GCS, Glasgow Coma Scale; PaCO₂, partial arterial carbon dioxide tension; PaO₂, partial arterial oxygen tension; RR, respiratory rate; SaO₂, arterial oxygen saturation. *Significant.

**Table 4 Changes in Glasgow Coma Scale, respiratory rate, and arterial blood gases at 12 h**

|                     | Group I (n=30) (mean±SD) | Group II (n=30) (mean±SD) |
|---------------------|--------------------------|----------------------------|
|                     | At admission             | At 12 h                    | P-value | At admission             | At 12 h                    | P-value |
| Clinical            |                          |                            |         |                          |                            |         |
| GCS                 | 14.47±0.68               | 14.63±0.81                 | 0.392   | 14.67±0.66               | 15±0                       | 0.010*  |
| RR (breath/min)     | 28.23±7.06               | 24.17±3.34                 | 0.006*  | 26.03±7.22               | 22.7±4.21                  | 0.033*  |
| ABG                 |                          |                            |         |                          |                            |         |
| pH                  | 7.32±0.08                | 7.35±0.07                  | 0.148   | 7.31±0.08                | 7.37±0.06                  | 0.001*  |
| PaCO₂               | 75.6±17.46               | 74.2±17.64                 | 0.757   | 74.13±16.8               | 67.07±12.3                 | 0.071   |
| PaO₂                | 65.53±14.77              | 70.5±16.3                  | 0.219   | 64.1±15.79               | 75.87±14.5                 | 0.004*  |
| SaO₂                | 88.9±7.3                 | 91.9±5.9                   | 0.086   | 84.23±17.51              | 92.7±6.1                   | 0.017*  |

ABG, arterial blood gas; GCS, Glasgow Coma Scale; PaCO₂, partial arterial carbon dioxide tension; PaO₂, partial arterial oxygen tension; RR, respiratory rate; SaO₂, arterial oxygen saturation. *Significant.
20 (66.7%) and the number of failed cases was 10 (33.3%). Failure rate was reported in patients with infection exacerbation in 70% of cases and heart failure in 30% of cases. In group II, the number of successful cases was 17 (56.7%) and that of failed cases was 13 (43.3%), in which the main cause of failure was reported in patients with infection exacerbation; however, the difference between the two groups was not significant ($P$=0.426). Although, no significant difference was found between the two groups as regards length of hospital stay ($P$=0.960), the duration spent on NIV was significantly shorter in group II than in group I [1 (1–1.25) vs. 2 (1–3), $P$=0.049] (Table 7).

### Discussion

When PaCO$_2$ is increased as in patients with acute hypercapnic RF, the patient has to increase minute ventilation to reduce hypercapnia. In acute hypercapnic RF, the respiratory muscles are failing to generate sufficient alveolar ventilation leading to hypoventilation and progressive hypercapnia. Thus, the means to improve this patient is to increase alveolar ventilation and reduce work of breathing [21]. Pressure–limited modes of NIV could decrease the amount of pressure against which the patient exhales, thus decreasing work of breathing without increasing peak inspiratory pressure [4]. On the other hand, volume–limited NPPV has the advantage to maintain adequate VT in the presence of changes in patient effort, chest wall compliance, or airway resistance [5]. Recently, hybrid modes that combine the benefit of both pressure–targeted and volume–targeted ventilation could be of great benefit in patients with hypercapnic RF. This study aimed to investigate the benefits the new ST/AVAPS mode in delivering NIV for patients with AHFR.

When monitoring patients with RF over 72 h, this study showed that, at 12 h, a significant improvement was observed in GCS, RR, and PH with a sustained improvement in PaO$_2$ and SaO$_2$ in group II; however, these parameters significantly improved at 48 h in group

#### Table 5 Changes in Glasgow Coma Scale, respiratory rate, and arterial blood gases at 48 h

|                      | Group I ($n$=30) (mean±SD) | Group II ($n$=30) (mean±SD) | $P$-value |
|----------------------|-----------------------------|-----------------------------|-----------|
| Clinical             |                             |                             |           |
| GCS                  | 14.47±0.68                  | 14.97±0.18                  | <0.001*   |
| RR (breath/min)      | 28.23±7.06                  | 24.37±3.44                  | 0.010*    |
| ABG                  |                             |                             |           |
| pH                   | 7.32±0.08                   | 7.4±0.06                    | <0.001*   |
| PaCO$_2$             | 75.6±17.46                  | 66.47±13.29                 | 0.026*    |
| PaO$_2$              | 65.5±14.77                  | 72.2±13.15                  | 0.070     |
| SaO$_2$              | 88.9±7.3                    | 93.07±4.35                  | 0.010*    |

**ABG, arterial blood gas; GCS, Glasgow Coma Scale; PaCO$_2$, partial arterial carbon dioxide tension; PaO$_2$, partial arterial oxygen tension; RR, respiratory rate; SaO$_2$, arterial oxygen saturation. *Significant.**

#### Table 6 Changes in Glasgow Coma Scale, respiratory rate, and arterial blood gases at 72 h

|                      | Group I ($n$=30) (mean±SD) | Group II ($n$=30) (mean±SD) | $P$-value |
|----------------------|-----------------------------|-----------------------------|-----------|
| Clinical             |                             |                             |           |
| GCS                  | 14.47±0.68                  | 14.93±0.37                  | 0.002*    |
| RR (breath/min)      | 28.23±7.06                  | 23.87±3.49                  | 0.004*    |
| ABG                  |                             |                             |           |
| pH                   | 7.32±0.08                   | 7.4±0.06                    | 0.000*    |
| PaCO$_2$             | 75.6±17.46                  | 66.47±13.29                 | 0.023     |
| PaO$_2$              | 65.5±14.77                  | 73.5±14.46                  | 0.039     |
| SaO$_2$              | 88.9±7.3                    | 93.7±7.2                    | 0.002*    |

**ABG, arterial blood gas; GCS, Glasgow Coma Scale; PaCO$_2$, partial arterial carbon dioxide tension; PaO$_2$, partial arterial oxygen tension; RR, respiratory rate; SaO$_2$, arterial oxygen saturation. *Significant.**

#### Table 7 Effect of BiPAP therapy on length of hospital stay and duration of noninvasive ventilation on both groups ($n$=60)

| Variables            | Group I ($n$=30) | Group II ($n$=30) | $P$-value |
|----------------------|------------------|-------------------|-----------|
| LoH stay (days)      | 13.5 (9–19)      | 13 (8–21)         | 0.960     |
| Duration of NIV (days)| 2 (1–3)          | 1 (1–1.25)        | 0.049*    |

Data are presented as median (interquartile range). LoH, length of hospital; NIV, noninvasive ventilation. *Significant.
I even with fluctuation in oxygen tension and saturation. As in our study, Claudett et al. [22] and Hussein and colleagues [23] observed a rapid and significant improvement in ABGs and consciousness (GCS) in both groups; however, patients treated with BiPAP S/T+AVAPS improved much faster compared with patients treated with the conventional strategy. Moreover, we showed improvement in \( \text{PaCO}_2 \) at 48 h in group II, whereas it appeared at 72 h in group I. Battisti et al. [24] compared manually adjusted pressures with self-adjusting pressure support in patients with acute RF, which produced a decrease in \( \text{PaCO}_2 \) levels in the latter group. In chronic patients with obstructive sleep apnea and alveolar hypoventilation syndrome, some authors reported a rapid improvement in \( \text{PaCO}_2 \) and sleep quality using VAPS [7,25,26], whereas others reported no difference between AVAPS and the conventional ST mode [7]. VAPS was studied for stable hypercapnic COPD patients in a limited number of previous recent clinical trials. Ekkernkamp et al. [27] compared noninvasive VAPS mode and high-intensity pressure support in 40 patients and revealed that there was a greater decrease in transcutaneous partial pressure of \( \text{CO}_2 \) during VAPS. However, other studies demonstrated no advantage of AVAPS versus pressure support in chronic stable COPD patients [28,29]. The ability of AVAPS mode to maintain the exhaled VT compared with BiPAP S/T mode alone as observed in our study could explain the faster improvement in oxygenation and hypercapnia consequently with improvement in alveolar ventilation.

Overall outcome in our study showed that, in group I, the number of successful cases was 20 (66.7%) and the number of failed cases was 10 (33.3%). In group II, the number of successful cases was 17 (56.7%) and the number of failed cases was 13 (43.3%). Outcome results were variable in previous studies. Intubation rate was reported to exceed 20% in a group of hypercapnic patients [30]. Plant et al. [31] reported an overall intubation rate of only 15% in patients receiving NIV in respiratory wards, but this rate reached 36% in patients with a pH less than 7.30. A recent study reported a rate of NIV failure of only 11% in severe COPD patients admitted in a specialized RICU [32]. Our results could not be compared with the previous studies due to variation in patients' population, patients' age, and the setting of the study (RICU, respiratory monitoring unit in a respiratory ward, general ICU, and both hospital ward and ICU). The relatively higher rate of failure in group II than in group I could be attributed to the fact that AVAPS mode was applied in more patients with infection exacerbation compared with BiPAP/ST mode. However, we reported a significantly shorter duration on NIV in group II compared with group I. Thus, AVAPS mode could be cost-effective on patients with AHRF.

**Conclusion**

Both ST/BiPAP and AVAPS modes are effective in the management of patients with AHRF. However, AVAPS modes showed more rapid and steady improvement in clinical parameters and shorter duration on NIV.

**Acknowledgements**

The authors thank the residents of Chest department, Assiut University Hospital, for helping in data collection. They also thank nurses in the Chest wards and in the RICU for helping in the follow-up of patients.

**Authors’ contribution:** Professor Ashraf Zin contributes to concepts, design of the study and definition of intellectual content. Professor Lamiaa H. Shaaban contributes to definition of intellectual content, manuscript review and takes responsibility of the integrity of the work as a whole from inception to published article. Shereen Farghaly contributes to literature search, clinical studies, data analysis, statistical analysis, manuscript preparation and manuscript review. Sarah Hashim contributes to data acquisition, data analysis and statistical analysis.

The manuscript has been read and approved by all authors, that the requirements for authorship as stated earlier in this document have been met, and that each author believes that the manuscript represents honest work, if that information is not provided in another form.

**Financial support and sponsorship**

Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

1. Meduri GU. Noninvasive positive pressure ventilation in patients with acute respiratory failure. *Clin Chest Med* 1996; 17:513–533.
2. Brochard L, Isabey D, Piquet J, Amaro P, Mancebo J, Messadi A, et al. Reversal of acute exacerbations of chronic obstructive lung disease by inspiratory assistance with mask. *N Eng J Med* 1990; 323:1523–1530.
3. Diaz O, Iglesia R, Ferrer M, Zavala E, Santos C, Wagner PD, et al. Effects of non-invasive ventilation on pulmonary gas exchange and hemodynamics during acute hypercapnic exacerbations of chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1997; 156:1840–1845.
4. Antonescu-Turcu A, Parthasarathy S. CPAP and bi-level PAP therapy: new and established roles. *Respir Care* 2010; 55:1216–1229.
5. Windisch W, Storre JH, Sorichter S, Virchow JC Jr. Comparison of volume- and pressure-limited NPPV at night: a prospective randomized cross-over trial. *Respir Med* 2005; 99:52–59.
6 Schoenhofer B, Sonneborn M, Haidl P, Böhrer H, Köhler D. Comparison of two different modes for noninvasive mechanical ventilation in chronic respiratory failure: volume versus pressure controlled device. *Eur Respir J* 1997; 10:184–191.

7 Murphy PB, Davidson C, Hind MD. Volume targeted versus pressure support non-invasive ventilation in patients with super obesity and chronic respiratory failure: a randomised controlled trial. *Thorax* 2012; 67:727–734.

8 Davidson C, Banham S, Elliott M, Gelder C, Glossop A, Kennedy D, et al. British Thoracic Society/Intensive Care Society Guideline for the ventilatory management of acute hypercapnic respiratory failure in adults. *Master consultation draft* 2016; 14:e000133.

9 Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD). COPD, global strategy for diagnosis, management, and prevention of COPD. Available at: http://www.goldcopd.org/guidelines-global-strategy-for-diagnosis-management.html. [Accessed 17 December 2015]

10 Piper AJ, Grunstein RR. Obesity hypoventilation syndrome, mechanisms and management. *Am J Respir Crit Care Med* 2011; 183:292–298.

11 Flency DC. Sleep in chronic obstructive lung disease. *Clin Chest Med* 1985; 6:651–661.

12 Mandell LA, Wunderink RG, Anzueto A, Bartlett JG, Campbell GD, Dean NC, et al. Infectious Diseases Society of America/American Thoracic Society consensus guidelines on the management of community-acquired pneumonia in adults. *Clin Infect Dis* 2007; 44:S27–S72.

13 Yancy CW, Jessup M, Bozkurt B, Butler J, Casey DE Jr, Drazner MH, et al. ACCF/AHA guideline for the management of heart failure: a report of the American college of cardiology foundation/American heart association task force on practice guidelines. Circulation 2013; 62:147–239.

14 Konstantinides S, Torbicki A, Gagnelli G, Danchin N, Galie N, et al. 2014 ESC guidelines on the diagnosis and management of acute pulmonary embolism. *Eur Heart J* 2014; 35:3033–3069.

15 Knauß WA, Draper EA, Wagner DP, Zimmerman JE. APACHE II: a severity of disease classification system. *Crit Care Med* 1985; 13:818–8829.

16 Vincent JL, Moreno R, Takala J, Willatts S, De Mendonca A, Bruining H, et al. The SOFA (Sepsis-related Organ Failure Assessment) score to describe organ dysfunction/failure. On behalf of the Working group on Sepsis-related Problems of the European Society of Intensive Care Med 1996; 22:707–710.

17 Le Gall JR, Lemeshow S, Saulnier F. A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study. *JAMA* 1993; 270:2957–2963.

18 Iankova A. The Glasgow Coma Scale: clinical application in emergency departments. *Emerg Nurse* 2006; 14:30–35.

19 Moretti M, Cilione C, Tampieri A, Fracchia C, Marchioni A, Nava S. Incidence and causes of non-invasive mechanical ventilation failure after initial success. *Thorax* 2000; 55:819–825.

20 Brochard L, Manoebo J, Wysocki M, Lotaso F, Conti G, Ruasa A, et al. Non invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease. *New Engl J Med* 1995; 333:817–822.

21 Evans TW, Albert RK, Angus DC, Bion JF, Chiche J, Epstein SK, et al. International Consensus Conferences in Intensive Care Medicine: non-invasive positive pressure ventilation in acute respiratory failure. *Intensive Care Med* 2001; 27:166–178.

22 Caudel KH, Caudel MB, Wong MCS, Martinez AN, Espinosa RS, Montalvo M, et al. Non invasive mechanical ventilation with average volume assured pressure support (AVAPS) in patients with chronic obstructive pulmonary disease and hypercapnic encephalopathy, *BMC Pulm Med* 2013; 13:12–17.

23 Hussein K. Non invasive spontaneous dual ventilation in critically ill patients with chronic obstructive pulmonary disease. *Egypt J Chest Dis Tuberc* 2016; 65:99–104.

24 Battistil A, Tassaux D, Bassin D, Jollet P. Automatic adjustment of noninvasive pressure support with a bilevel home ventilator in patientswith acute respiratory failure: a feasibility study. *Intensive Care Med* 2007; 33:632–638.

25 Storee JH, Seuthe B, Fiechter R, Milioglou S, Dreher M, Sorichter S, et al. Average volume-assured pressure support in obesity hypoventilation: a randomized crossover trial. *Chest* 2006; 130:815–821.

26 Ambrogio C, Lowman X, Kuo M, Malo J, Prasad AR, Parthasarathy S. Sleep and non-invasive ventilation in patients with chronic respiratory insufficiency. *Intensive Care Med* 2009; 35:306–313.

27 Ekkernkamp E, Storee JH, Windsch W, Dreher M. Impact of intelligent volume-assured pressure support on sleep quality in stable hypercapnic chronic obstructive pulmonary disease patients: a randomized, crossover study. *Respiration* 2014; 88:270–276.

28 Cristofulli E, Manni G, Kidonias M, Trianni L, Cini EM. Subjective sleep quality during average volume assured pressure support (AVAPS) ventilation in patients with hypercapnic COPD: a physiological pilot study. *Lung* 2009; 187:299–305.

29 Oscroft NS, Aih, Gulati A, Davies MG, Quinnell TG, Sneedson JM, Smith IE. A randomised crossover trial comparing volume assured and pressure preset noninvasive ventilation in stable hypercapnic COPD. *COPD* 2010; 7:398–403.

30 Nouira S, Boukel F, Bouda W, Kerkari W, Belfaif K, Boubaker H, et al. Non-invasive pressure support ventilation and CPAP in cardiogenic pulmonary edema: a multicenter randomized study in the emergency department. *Intensive Care Med* 2011; 37:249–256.

31 Plant PK, Owen JL, Elliott MW. Early use of non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease on general respiratory wards: a multicentre randomised controlled trial. *Lancet* 2000; 355:1931–1935.

32 Carrillo A, Ferrer M, Gonzalez-Diaz G, Lopez-Martinez A, Llamas N, Alcazar M, et al. Non-invasive ventilation in acute hypercapnic respiratory failure due to obesity-hypoventilation syndrome and COPD. *Am J Respir Crit Care Med* 2012; 186:1279–1285.