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Respiratory muscle unloading during auto-adaptive non-invasive ventilation☆

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Summary
Rationale: Non-invasive ventilation (NIV) has been shown to improve clinical outcomes in acute and chronic hypercapnic respiratory failure. A new timed, automated, auto-adaptive non-invasive ventilatory mode (TA-mode) has been recently introduced.
Objective: To investigate the degree of respiratory muscle unloading with this new mode in comparison to assisted (S-mode) NIV in healthy individuals.
Methods: Work of breathing, pressure time product and transdiaphragmatic pressure time product were measured during unassisted breathing, assisted and TA-mode-NIV in eight healthy, awake volunteers at inspiratory pressures of 20 and expiratory pressures of 4 hPa.
Results: Assisted and TA-mode-NIV reduced the work of breathing by 50 and 89.1%, pressure time product by 61.5 and 72.6% and transdiaphragmatic pressure time product by 77 and 88.7%, respectively when compared to unassisted breathing. The degree of respiratory muscle unloading was higher during TA-mode-NIV when compared to assisted non-invasive ventilation (work of breathing $p < 0.001$, pressure time product $p = 0.04$ and transdiaphragmatic pressure time product $p = 0{,}01$).
Conclusion: TA-mode-NIV achieved significant higher levels of respiratory muscle unloading in healthy individuals when compared to assisted non-invasive ventilation.

Introduction

There is robust evidence that non-invasive ventilation (NIV) decreases work of breathing, improves gas exchange and relieves dyspnea in acute and chronic respiratory failure.[1–4] NIV unloads the respiratory muscles and thereby increases patient mobility[5] and endurance.[6] The degree of respiratory muscle unloading depends on the ventilatory mode as well as on the level of ventilatory support.[7–9]

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Trigger sensitivity determines the energy that has to be spent before the ventilator will support the breathing cycle.[10,11] Work to trigger the ventilator can be substantial and is reported to be as high as 65% of the work of passive inflation during invasive ventilation[12–14] and up to 39% during NIV.[15] During assisted mode ventilation patient effort does not abruptly cease with the onset of gas delivery by the ventilator and muscle effort is still present after the ventilator has started to support the breath.[13] Reduction of the breath initiating effort is likely to increase the degree of respiratory muscle unloading. This could be achieved by application of controlled ventilator modes during NIV. Controlled NIV is feasible[16] but carries the risk of patient–ventilator asynchrony with increased workload during inspiration and expiration.[17,18] A new ventilator mode (TA = timed automated adaptive mode, Weinmann, Hamburg, Germany) has been introduced into the market.[19] This mode is programmed to analyse and closely follow the patients' own respiratory pattern in a controlled fashion.

The present study compares the TA mode to the commonly used assisted mode during NIV by measuring the degree of inspiratory muscular unloading in healthy and awake individuals to confirm or refute the presence of more effective respiratory muscle unloading.

Method

The institutional review board (Medical Association, Wilhelms University Muenster, Germany, application No. 2006-532-f-S) approved the protocol. From previous unpublished data we estimated Cohen's d to be 3.14 and the effect size to be 0.84.

Power analysis (Gpower 3.0.10) determined the number of required measurements to be $n = 7$. We recruited eight healthy volunteers (one female) and obtained informed consent. Lung function tests were performed using a body plethysmograph (Masterlab, Jaeger, Wuerzburg, Germany). Subject characteristics are shown in Table 1.

For each individual a suitable face mask was selected and adjusted to achieve optimal air tightness and comfort. Preferably, nose-masks were selected, however a full face mask was necessary in one individual to accomplish optimal fit. Volunteers were positioned in a 45 degree upright position using a recliner chair. Two balloon catheters (47-8605, Ackrad Laboratories, Cranford, NJ, USA) were introduced through the nostrils and advanced with aid of active swallowing into the stomach. Catheters were passed through the mask by means of two small bore holes which then were sealed with plastinate to achieve air tightness (Fig. 1). We connected catheters to capacitative pressure transducers (DP 15-36,Validyne, Northridge, CA, USA) connected to an amplifier (CD223, Validyne, Northridge, CA, USA). A flow sensor (4700 Series, 0-160 LPM, Hans Rudolph Inc., Kansas City, MO, USA) was attached between mask and whisper valve and connected to a pneumotach amplifier (1110, Hans Rudolph Inc, Kansas City, MO, USA). We captured data on a personal laptop computer using a customized Lab View Program (Version 6, National Instruments, Austin, TX, USA) after A/D conversion (PMD-1208LS converter, Meilhaus Electronics, Puchheim, Germany) at a sampling rate of 100 Hz.

We calibrated the catheters after inflation with 2.5 cc of air and retracted one catheter until we obtained opposing pressure signals and confirmed position with the occlusion method.[20]

Table 1 Demographic and lung function data, forced expiratory volume in one second (FEV_1), vital capacity (VC).

	Mean	±SD
Age (years)	38	9
BMI	22.6	2.6
FEV_1 (l)	4.8	0.5
FEV_1% predicted	112.4	11.4
VC (l)	5.6	0.6
VC % predicted	104.1	11.7

Ventilator equipment, pressures and modes

We used a Ventilogic non-invasive ventilator (Weinmann, Hamburg, Germany).

We selected an inspiratory pressure (P_I) of 20 hPa for the following reasons: (1) NIV in chronic hypercapnic patients has been shown to be effective above a threshold of 18 hPa.[21] (2) Selecting pressures higher than 20 hPa have resulted in marked hyperventilation of the healthy volunteers.[22] We selected the lowest possible expiratory pressure (P_E, 4 hPa) in the absence of airway collapse.

These settings resulted in an effective driving pressure of 16 hPa, a number shown to be effective in hypercapnic patients.[21]

Modes

We applied NIV using assisted (S = Spontaneous) as well as TA mode ventilation.

During assisted ventilation inspiratory and expiratory trigger sensitivity was set to 5 (possible range 1–6, 6 being most sensitive), P_I was set to 20 hPa and P_E to 4 hPa.

We measured the effort during unassisted breathing with the subjects breathing spontaneously through the flow sensor attached through the mask while the NIV-tubing system was disconnected.

Description of TA mode

To set up the TA mode one has to select P_I, P_E, a target respiratory rate and a range of allowance as well as the type of expected underlying disease (R = Restrictive, O = Obstructive, N = Normal). The TA mode begins with an analysis phase. During this phase, a continuous pressure of 4 hPa is maintained to guarantee effective carbon dioxide washout through the whisper valve. During this phase, the ventilator analyzes the patients own flow profile by integration of flow and time (Fig. 2). Once the ventilator senses a stable profile (time and flow measurements within a predefined range of allowance), the ventilator will increase P_I over five consecutive breaths in steps of 60–70–80–90–100% of preset P_I (Fig. 2). During the inspiratory phase, P_I will be adjusted over