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Respiratory muscles during ventilatory support

J.W. Fitting

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ABSTRACT: Knowledge of the fate and behaviour of the respiratory muscles during ventilatory support is important for the guidance of clinical care. Full support facilitates muscle metabolic repletion, but exposes them to the risk of disuse atrophy. The effect of partial support varies according to the selected mode: assisted mechanical ventilation (AMV) and synchronized intermittent mechanical ventilation (SIMV) result in much less respiratory muscle rest than generally anticipated. On the other hand, inspiratory pressure support (IPS) is able to rest the respiratory muscles and to prevent fatiguing contractions. Opposite interventions have been proposed in case of difficult weaning: either to unload the respiratory muscles by using partial support, or to overload them according to a training programme. The optimal strategy is not known and may combine both approaches.

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Division de pneumologie, Centre Hospitalier Universitaire Vaudois, Lausanne, Switzerland.

Correspondence: J.W. Fitting
Division de pneumologie
CHUV
1011 Lausanne
Switzerland

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In recent years, considerable information has been collected on the behaviour of the respiratory muscles during complete, partial or noninvasive ventilatory support.

Full ventilatory support

Full ventilatory support is achieved by controlled mechanical ventilation (CMV), where the ventilator provides inflations at a preset volume and frequency. Respiratory muscle rest is attained if the patient is completely relaxed, which most often necessitates sedation and curarization. The main benefit of resting the respiratory muscles lies in their metabolic recovery. Respiratory muscle depletion of glycogen, creatine phosphate and adenosine triphosphate (ATP) has been documented in patients with chronic obstructive pulmonary disease (COPD) and acute respiratory failure, and was corrected after a period of mechanical ventilation [1]. Although this result was observed after several weeks of treatment, animal experiments suggest that metabolic repletion of muscles requires only several hours to a few days. Longer rest may be required for recovery if respiratory muscle fibres have been damaged by work overload.

On the other hand, complete rest of the respiratory muscles exposes them to the risk of atrophy. Skeletal muscle atrophy develops rapidly during complete rest, but the rate of respiratory muscle atrophy during full ventilatory support is not precisely known. In a preliminary study, ANZUETO *et al.* [2] reported a 46% fall of maximal transdiaphragmatic pressure and a 37% fall of ventilatory endurance in three baboons after 11 days of CMV.

Partial ventilatory support

Partial ventilatory support may be initiated for various reasons. Firstly, because it is virtually impossible to prevent a conscious subject from breathing, and therefore to impose CMV. Secondly, to somewhat load the respiratory muscles in order to avoid the risk of muscle atrophy during prolonged mechanical ventilation. Thirdly, to unload the respiratory muscles when they seem unable to take over the entire work of breathing at the time of weaning, because of weakness or fatigue. Whatever the reason, knowledge of the degree of respiratory muscle rest provided by the different modes of partial support is important, in order to guide the care of these patients.

Assisted, or assist-control, mechanical ventilation (AMV) is a mode in which the ventilator provides assisted breaths of a preset volume in response to every patient-initiated inspiratory effort. Thus, the work of breathing performed by the patient (W_p) could be expected to be minimal. However, this would necessitate a very rapid inhibition of inspiratory muscles after the initial effort, such that the ventilator would take over most of the work of breathing. This assumption was challenged by MARINI *et al.* [3], who showed that during AMV the W_p was approximately 60% of that during spontaneous breathing. They also found that the main determinants of W_p during AMV were the inspiratory drive and the inspiratory muscle strength. This observation implied that the inspiratory muscles were not easily inhibited during AMV. This was confirmed by FLICK *et al.* [4] who showed electromyographic (EMG) activity of the diaphragm persisting during the complete assisted breath in AMV.

During synchronized intermittent mechanical ventilation (SIMV), the patient receives assisted breaths at a preset frequency and is also able to breathe spontaneously

between assisted cycles. In principle, the W_p can be modulated by simply varying the rate of assisted cycles per minute. This view assumes that the respiratory centres of the patient are able to recognize very quickly which cycle is assisted and which is not, in order to inhibit, or on the contrary, to pursue the inspiratory effort. This assumption was also challenged by MARINI *et al.* [5], who assessed the W_p during various levels of SIMV support, and compared it between assisted and spontaneous cycles. They found that the W_p decreased with increasing SIMV support; however, in lesser proportion. Moreover, the W_p was either similar or only marginally different between assisted and spontaneous breaths.

Using electromyography, IMSAND *et al.* [6] further explored the neuromuscular output directed to the inspiratory muscles during SIMV. They found that the duration of EMG activity of the diaphragm and of the sternocleidomastoid muscle were unchanged with various levels of SIMV support, as well as between assisted and spontaneous breaths. The amplitude of integrated EMG was also similar between assisted and spontaneous breaths. The cumulative activity of each muscle was calculated by adding the amplitudes of integrated EMG over 1 min. This activity was practically unchanged by moderate levels of support (20–50% of total ventilation provided by the ventilator), and was decreased by less than 40% at higher levels of support. These results indicate that the degree of respiratory muscle rest achieved by SIMV is much less than anticipated. They also demonstrate that the inspiratory neural output is maintained constant for a given average load, and is not regulated on a breath-by-breath basis in SIMV.

With inspiratory pressure support (IPS) ventilation, the patient quickly receives a positive airway pressure after he has triggered the machine by an inspiratory effort. The pressure is maintained constant throughout inspiration until a preset fall in airflow occurs, usually to 25% of peak inspiratory flow. The effect of IPS in eight patients who had previously failed weaning trials was described by BROCHARD *et al.* [7]. During a trial of spontaneous breathing without IPS, all patients but one showed EMG signs of fatiguing diaphragmatic contractions. With increasing levels of IPS, fewer patients showed signs of fatigue, and with 20 cmH₂O of IPS, all of them were able to sustain the trial without electrical sign of fatigue. The amplitude of the integrated EMG of the sternocleidomastoid muscle markedly fell with increasing levels of IPS, and was virtually zero when the level of IPS was sufficient to prevent signs of diaphragmatic fatigue. Thus, a higher degree of respiratory muscle rest is achieved by IPS than by the other usual modes of partial support.

Noninvasive ventilatory support

During recent years, noninvasive mechanical ventilation has gained popularity, for treating either acute or chronic ventilatory failure. It can be provided either by intermittent negative pressure around the thorax, or by intermittent nasal or facial positive pressure. Negative

pressure ventilation, by means of an iron lung, a cuirass, or a poncho, is able to offer respiratory muscle rest. However, several groups showed that the degree of EMG inhibition achieved by negative pressure ventilation is variable among individuals, from very partial to nearly complete. The degree of inhibition is higher in patients accustomed to the technique.

Positive pressure ventilation through a nasal or facial mask may provide a marked inhibition of inspiratory muscles, even in patients with acute ventilatory failure [8]. The general impression of the superiority of positive pressure ventilation has been confirmed by BELMAN *et al.* [9], who compared both methods in the same patients. The degree of inhibition of diaphragmatic EMG activity was significantly greater with positive pressure than with negative pressure ventilation.

Optimal strategy: to load or to unload?

Weaning from mechanical ventilation may prove difficult when there is a mismatch between the ventilatory load and the capacity of the respiratory muscles. In such a situation, the usual practice is to unload the respiratory muscles with partial support, and to very gradually withdraw this support until the patient is able to take over the entire work of breathing. However, an opposite strategy has been proposed and may also prove useful. ALDRICH *et al.* [10] applied a training programme of the respiratory muscles to 27 patients who had previously failed multiple weaning trials. The patients had to breathe for 30 min·day⁻¹ through an inspiratory resistance, which was progressively increased over the sessions. Twelve patients (44%) could be weaned, five (19%) could be discharged with nocturnal ventilation, and 10 (37%) could not be weaned.

This report poses the question of whether the respiratory muscles should be unloaded or loaded when they fail during weaning. Although seemingly paradoxical, the idea of overloading failing muscles obeys a certain logic. Muscle training is governed by the principle of overload, such that a muscle improves its performance only if it is exerted above its usual level of activity. Thus, fatigue plays a greater role than the workload itself for improving muscle performance [11]. In case of difficult weaning, the usual attitude is to unload the respiratory muscles in order to avoid respiratory muscle fatigue. It might be that fatigue should be attained, but in brief periods and controlled conditions, in alternation with periods of rest. However, the optimal conditions of loading and unloading of the respiratory muscles during weaning are not known.

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