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Intelligent Ventilation in the ICU: Technology Improving Patient Outcomes

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Intelligent ventilation is the appropriate application of a suitable mode of ventilation in each clinical situation with online, automated adjustment of the mode and level of support when the patient's respiratory needs alter and with automated weaning as soon as possible to reduce the time of mechanical ventilator support and days in the ICU.

Using intelligent ventilator technology most patients can be automatically ventilated (optimally) according to the least work of breathing fit of the measured mechanics of the lungs and chest wall. Simply by providing the maximal alveolar ventilation for the lowest needed minute ventilation, and therefore the least dead space ventilation, the resulting blood gases are likely to be the best possible for the state of the lungs. In addition, the importance of preventing the development of intrinsic positive end expiratory pressure (Auto PEEP) while maximising alveolar ventilation, particularly in patients with obstructed airways, was recognised. Thus, the initial development of adaptive support ventilation (ASV) machines without the need for end tidal CO2 feedback in the closed loop, proved the reality of the least work of breathing philosophy in the optimal mechanics of ventilation of most patients.

Further development of the Intellivent™ (Hamilton Medical, Bonaduz, Switzerland) closed loop system, using online capnography and pulse oximetry with artefact elimination, has extended the capability of intelligent ventilation to include automating the minute ventilation target as well as the FiO2 and PEEP settings.

Our clinical experience with these forms of intelligent ventilation is that we shorten patient ventilation days, reduce morbidity associated with mechanical ventilation and generally improve patient outcomes. An added benefit that we notice on a daily basis is a dramatic reduction in medical and nursing staff workload as intelligent ventilation eliminates the need, hour by hour, to make changes to ventilator settings to apply weaning protocols.

Introduction

Pressure support ventilation (PSV) is the most wellknown, basic and effective form of closed loop control ventilation and is widely used today. The clinician sets a target pressure (the pressure support setting), and flow (the output) is automatically adjusted to maintain that pressure throughout inspiration. The ventilator monitors airway pressure (the target), and the control algorithm continuously modulates the flow (the output) to achieve the desired pressure. Patients are usually most comfortable on this simple form of closed loop support. However, the amount of pressure support (the PS target) needs to be constantly updated and, when weaning is desired, gradually reduced by the clinician hour by hour.

The basis of intelligent ventilation is the application of the closed loop automated algorithm of the adaptive support ventilation (ASV) technology, which uses a number of different modes, including PSV and pressure controlled synchronised intermittent mandatory ventilation (SIMV) as needed by the patient, (Mireles-Cabodevila et al. 2009; Conti and Costa 2010). ASV intelligently and automatically adapts the respiratory rate and level of ventilator pressure to the patients' passive and active respiratory mechanics (Branson 2000; Campbell et al. 2001; Tassaux et al. 2002). ASV warrants that the pre-determined target minute ventilation, based on ideal body weight and percent minute volume settings, is delivered to the patient.

Using online, breath-by-breath analysis of lung function, the ventilator is driven by a programmed computer to provide optimal alveolar ventilation, according to the patient’s changing requirements (Linton 2001; Brunner and Iotti 2002). The programming is based on a concept of maximal energetic benefit: at any single breath the ventilator selects the respiratory rate target (and hence the tidal volume target) that corresponds to the minimal work of breathing of the patient- ventilator unit.

The automatic selection of targets is based on data for series dead space and expiratory time constant, which are provided by a lung function analyser that is communicating continuously with the ventilator's controller. The lung function analyser also calculates compliance, resistance and air trapping (residual end expiratory flow), in order to optimise respiratory flow patterns and the inspiration: expiration ratio. Target volume and rate are calculated specifically for each patient in order to achieve the set target minute volume according to the patient's lung mechanics (compliance, resistance, air trapping, dead space and expiratory time constant) and peak airway pressures.

At any breath, the controller compares target and actual data for tidal volume and respiratory rate, and programmes the mandatory rate and inspiratory pressure to be applied in the next breath, to approach the desired targets (Laubscher, Frutiger et al. 1994; Laubscher, Heinrichs et al. 1994; Weiler et al. 1994). Inspired pressures are either delivered using pressure control in apnoeic patients or pressure support in spontaneously breathing patients.

Our Experience with ASV

We recently audited our experience with ASV in our Medical Intensive Care Unit over the past decade (Linton 2012; Sviri et al. 2012) (See Tables A and B). Mean length of ventilation (all modes) was more than 10 days with a median of 6 days. Sedation was required in 812 patients (67%) for a median length of 2 days. Nine hundred and forty eight patients were ventilated with ASV for more than 50% of the time (93%). Sixty-eight (6%) patients required transition from ASV mode to pressure control mode (PCV). The primary indication for switching from ASV to PCV was to satisfy our technical requirement for a stable tidal volume to allow administration of inhaledNitric Oxide (NO). Respiratory complications included ventilator-associated pneumonia (VAP) in 288 patients (23.6%); pneumothorax developed in less than 1% of all patients ventilated with ASV. Weaning from mechanical ventilation was mostly (86%) performed with ASV.

ASV requires that an adequate and optimal target minute volume is set according to the ideal body weight (Dongelmans et al. 2008). Few manual manipulations of the ventilator are required (Petter et al. 2003), and the automated controller provides rapid adaptation to changing ventilator needs of ventilated patients (Linton 2001; Lellouche and Brochard 2009). Our unit does not employ respiratory therapists trained in setting ventilators. Such changes are therefore left to the medical staff in the ICU, who are not always available to quickly respond to changing ventilation requirements. The ASV mode reduces the need for manipulation of the ventilator settings as it adjusts automatically to altered lung mechanics and patients' effort, compensating for reduced staffing levels.

Experience of Others Using ASV

Previous studies have tested the efficiency, safety, and adaptability of ASV in various lung diseases and in patients undergoing general anaesthesia, during position changes and transition between two- and one-lung ventilation (Weiler et al. 1994; Weiler et al. 1998; Belliato et al. 2004). Tassaux and colleagues demonstrated improvement in patient- ventilator interaction and reduction in signs of asynchrony with ASV compared with SIMV and PS in patients during early weaning with partial ventilator support (Tassaux et al. 2002). In their study, which reports the use of ASV as the primary mode of ventilation in a mixed ICU (322 patients), Arnal and colleagues found that ASV was used in 98% of invasive ventilation days, and appropriately selected different rate/volume combinations for patients with different types of underlying lung disease, including acute respiratory distress syndrome (ARDS) and chronic obstructive pulmonary disease (COPD) (Arnal et al. 2008).

ASV has been shown to hasten weaning from ventilation compared to other modes (Gruber et al. 2008). It can appropriately decrease ventilator support in patients with chronic respiratory failure who tolerated a conventional weaning trial, suggesting that this mode may facilitate respiratory weaning (Linton et al. 1994). ASV is practicable as a respiratory weaning protocol in post-surgical patients; it may accelerate tracheal extubation and simplify ventilatory management in patients after cardiac surgery (Sulzer et al. 2001; Petter et al. 2003). It has also been shown to be a safe weaning modality as patient demands are adequately met during weaning from ventilation (Linton et al. 1994; Jaber et al. 2009). In our experience ASV is highly suitable for patients with chronic obstructive lung disease and for weaning most patients from ventilatory support. There was only minimal need to convert any patient from ASV to other modalities during the weaning phase.

ASV has been shown to be safe in a model of ARDS, by limiting peak pressures and reducing tidal volumes (Sulemanji et al. 2009). In our own practice we have found that most patients in our database with ARDS tolerated ASV well throughout the required ventilation of their lung disease. However, a minority of patients (6%) required transition to pressure controlled ventilation, due to patient-ventilator asynchrony, severe hypoxia necessitating inhaled NO or a desire by the attending clinicians to provide more inverse ratio ventilation than the ASV controller allowed.

ASV has been the sole mode of ventilation in some chronic care facilities in Israel for several years (Linton et al. 2006), and has been shown to be cost-effective, safe and efficient in ventilating and weaning patients with chronic respiratory failure. ASV automatically allows weaning of most patients and therefore requires fewer manipulations of the ventilator during the weaning process.

It is important to realise that both the ASV and the Intellivent™ technology have the capacity to 'recognise' the development of excessive autoPEEP and adjust the I:E ratio accordingly in an attempt to limit the autoPEEP and thus prevent the development of tension pneumothorax, which is a feared complication of mechanical ventilation in severe ARDS. There is clearly a difference of international expert opinion on the ideal PEEP to use, and the temporary use of pressure controlled ventilation (PCV) is an acceptable alternative in more heavily sedated and paralysed patients when inhaled NO is used, to optimise patient-ventilator synchrony and oxygenation.

Intellivent

Intellivent-ASV® (Hamilton Medical, Bonaduz, Switzerland) is a recently released development of ASV that automatically adjusts both ventilation and oxygenation parameters (FiO2 and PEEP) (Arnal et al. 2012). Minute volume is adjusted according to end tidal CO_2 (ETCO2) measured continuously, and oxygenation is adjusted according to SpO2 measurements. The only parameter that the physician sets is the patient's ideal body weight. It utilises proprietary algorithms to set optimal ventilation parameters and responds to dynamic changes in SpO2 and ETCO2. The algorithms are calibrated to different disease patterns (such as ARDS, head injury and chronic obstructive lung disease), which the user selects. The range of acceptable settings is also adjustable by the user and adds a level of safety and individuality. This mode of ventilation has been on trial in our ICU over the past year in an in-house, non-funded clinical study. Our preliminary experience has been that the Intellivent™ technology is safe, and seems able to optimise the PEEP level and reduce the FiO2 faster than we usually do, in a broad range of ICU patients.

Conclusion

ASV is an acceptable mode of ventilation for complicated medical patients in the MICU with a good weaning success rate and low complication rate. In our recent experience with a number of patients with critical ARDS, or severe restrictive lung disease e.g. pneumonitis, interstitial fibrosis and chest stiffness, Intellivent™ appears to be able to optimise the PEEP and bring the FiO_2 down faster than we were doing with ASV.

The online monitoring of FiO_2 and PEEP with automated adjustment to the target minute ventilation in ASV as well as the visual monitoring of heart-lung interaction parameters, as provided for by the Intellivent™ technology, enhances the automated ventilator's capability to monitor the patients. This completely automated system seems to avoid any need for manual changes to the Minute Volume Target Percentage or to the set PEEP and FiO2 settings.

Conflict of Interest Statement

The authors declare that they have no conflict of interest in the work, preparation and content of this article.

Disclosure

This invited paper includes a review and update of recent publications by the authors.

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