Automation of Weaning in Children

61

Philippe Jouvet, Stefan Mersmann, and Marc Wysocki

Educational Aims

With this chapter, the reader will be able:

- To describe the principles used in the modification of ventilator parameters by SmartCare/PS®
- To describe the principles used in the modification of ventilator parameters by IntelliVent®
- To describe the current clinical knowledge of these two automated modes for mechanically ventilated children

This chapter describes the basics and the clinical experience with two explicit computerised protocols (ECP) implemented in commercialised ventilators: Smartcare/PS® by Draeger Medical (Germany) and IntelliVent® by Hamilton Medical (Switzerland). These two ECPs manage ventilation, without the need of caregivers' intervention but under their supervision. SmartCare/PS® is an autopiloting, knowledge-based software application that provides an ECP for the automated control of pressure support ventilation. IntelliVent® is an explicit computerised protocol for the automated control of minute volume, PEEP and FiO_2 in adaptive support ventilation (ASV). The main innovation of the two ECPs is the use of ET_{PCO_2} as a surrogate for blood gas PCO_2, to decrease or increase ventilatory support. IntelliVent® also uses SpO_2 to decrease or increase PEEP and FiO_2. The two ECPs were studied in children during the weaning phase and the first clinical studies are promising. However, further clinical trials are needed to better assess the efficacy and tolerance of these two ECPs in children and to develop ECP that are dedicated to all ages including neonates.

P. Jouvet, MD, PhD (✉)
Pediatric Intensive Care Unit, Sainte Justine Hospital,
3175 chemin Côte Sainte Catherine,
Montréal, QC 23542, Canada
e-mail: philippe.jouvet@umontreal.ca

S. Mersmann, MSc
Research and Development, Clinical Software Solutions, Draeger Medical AG & Co. KG,
Moislinger Allee 53-55, 23542 Luebeck, Germany
e-mail: stefan.mersmann@draeger.com

M. Wysocki, MD
Research Center, Sainte Justine Hospital,
3175 chemin Côte Sainte Catherine,
Montréal, QC 23542, Canada
e-mail: mwysocki@hamilton-medical.ch

61.1 Introduction

Discontinuing mechanical ventilation as soon as it is no longer needed is crucial in preventing respiratory and prolonged sedation complications. The weaning process is described in a previous chapter (see section on weaning Part XXII) and can be summarised in six steps according to the sixth international consensus conference on intensive care medicine (Boles et al. 2007) including (1) suspicion that weaning may be possible, (2) assessment of readiness to

P.C. Rimensberger (ed.), *Pediatric and Neonatal Mechanical Ventilation*,
DOI 10.1007/978-3-642-01219-8_61, © Springer-Verlag Berlin Heidelberg 2015

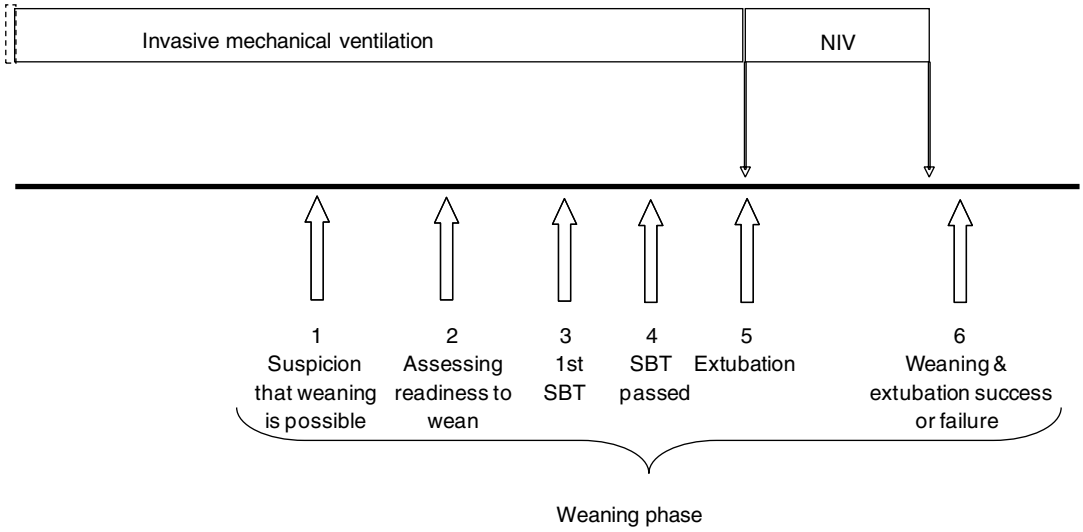

Fig. 61.1 Schematic representation of the different steps during weaning from mechanical ventilation in children

wean, (3) spontaneous breathing trial (SBT) performed, (4) SBT passed, (5) extubation and (6) assessment of successful or failure of extubation (Fig. 61.1). Between each steps mechanical ventilation has to be adapted to reach the next step until no ventilator support is needed anymore. At present, two explicit computerised protocols on weaning children from mechanical ventilation are implemented in commercialised ventilators. This chapter describes these two explicit computerised protocols: Smartcare/PS® by Draeger Medical (Germany) and IntelliVent® by Hamilton Medical (Switzerland).

61.2 SmartCare/PS®: Draeger Medical

SmartCare/PS®—PS stands for pressure support—is an autopiloting, knowledge-based software application that provides an ECP for the automated control of pressure support ventilation. This ECP manages, without the need of caregivers intervention but under their supervision, the four following therapeutic procedures: (1) automatic adaptation of the pressure support level to keep the patient inside a "zone of respiratory comfort", i.e. normal ventilation (see below); (2) a strategy to gradually and progressively decrease the level of pressure support level; (3) an automated SBT when the patient reaches a minimum ventilatory support; and (4) a recommendation of separation from the ventilator when the SBT is successfully passed (Table 61.1).

SmartCare/PS® is available on Draeger's Evita XL and the latest generation of Draeger Medical ventilators: Evita Infinity V500. It is applicable in two applications that slightly differ: (a) for patients with ideal body weight (IBW) between 15 kg and 35 kg as well as for (b) patients with IBW between 36 kg and 200 kg. The ECP comprises of the three different phases "adaptation", "observation" and "maintain" to perform ventilation procedures (1) to (4). It will also manage patient instabilities, e.g. transient tachypnoea, and it can cope with certain patient care situations like suctioning and pauses during specialised therapeutic situations like nebulisations or during specific ventilator alarm.

61.2.1 Basics of SmartCare/PS®

61.2.1.1 Initiation of SmartCare/PS®

Initiating SmartCare/PS® is recommended when a child, with IBW greater than 15 kg, fulfils ready-to-wean criteria that were used in two prospective clinical studies (Jouvet et al. 2007;

Table 61.1 Characteristics of the SmartCare/PS® Draeger Medical and IntelliVent® Hamilton Medical explicit computerised protocols

Characteristics	SmartCare/PS®	IntelliVent®
Mode of ventilation	PS	ASV
Body weight range for use (kg)	≥15	≥7
Weaning steps managed (see Fig. 61.1)	2–4	1–4
Primary goal of the ECP	Wean patient while maintained in normal ventilation (see Table 61.2)	To maintain in a normal ET_{PCO_2}, RR and SpO_2 ranges
Initial settings	IBW, humidification system, medical history	IBW, medical history
Setting modification displayed but need caregiver prescription (open loop)	No	Yes
Input data	$_{2min}V_t$, $_{2min}$RR, $_{2min}ET_{PCO_2}$, PEEP, PS level, ventilator messages	RR, ET_{PCO_2}, SpO_2
Rules displayed to caregivers when applied	No	±
Output data	Parameter display, e.g. PS level Therapeutic messages "SBT successful"	MV, PEEP, FiO_2 SBT duration
SBT	Yes	Yes
SBT duration	1–2 h according to initial PS level (Jouvet et al. 2007)	Adjustable
Recommendation of separation from the ventilator	Yes	No

PS pressure support, *ASV* adaptive support ventilation, *IBW* ideal body weight for height, V_t tidal volume, *RR* respiratory rate, ET_{PCO_2} end-tidal PCO_2, SpO_2 pulse oxygen saturation, $_{2min}V_t$, $_{2min}RR$ *or* $_{2min}ET_{PCO_2}$ mean value on 2 min of V_t, RR or ET_{PCO_2}, *MV* minute volume, *PEEP* positive end-expiratory pressure, FiO_2 inspired fraction of oxygen, *PIP* positive inspiratory pressure, *SBT* spontaneous breathing trial

Jouvet et al. 2010a). These weaning criteria are as follows:

- The attending physician evaluates that the patient is able to breathe spontaneously or the patient is already breathing spontaneously.
- No significant vasopressors or inotropic medications, excluding digoxin or low-dose dopamine (≤5 μg/kg/min).
- Slight or no endotracheal tube gas leakage ($[V_{ti}-V_{te}]/V_{ti}$ ≤20 %).
- Mechanical ventilation with a plateau pressure above PEEP ≤25 cmH_2O.
- PEEP ≤8 cmH_2O.
- FiO_2 ≤60 % with SpO_2 ≥95 %.
- Pressure support test passed. During the pressure support test, the patient is mechanically ventilated in pressure support mode for 30 min, with a level of pressure support set to ±5 cmH_2O of the current plateau pressure. The pressure support test is stopped before 30 min if the patient shows evidence of respiratory distress (respiratory rate below 10 breaths per min or above 40 breaths per minute and FiO_2 >60 % in order to obtain a SpO_2 ≥95 %). The test is passed when, after 30 min, the patient remains stable with a respiratory rate between 10 and 40 breaths per min, an expiratory tidal volume higher than 6 ml/kg and SpO_2 ≥95 % with FiO_2 ≤0.6.

When the child fulfils all the above mentioned criteria, IBW, which is also a surrogate for lung volume (see chapter on explicit computerised protocols), is prescribed on the ventilator by the user. The next step is to prescribe the humidification system and the medical history (presence or not of neurologic disorders or COPD) if the child's IBW is above 35 kg. These user-given settings will determine certain thresholds and specific rules of the ECP (Table 61.2).

Table 61.2 Normal ventilation definition in SmartCare/PS®

Definition	Parameters value	IBW ≤35 kg	35 kg <IBW ≤55 kg	IBW >55 kg
Normal ventilation:	RR low (bpm)	18	10–15	10–15
RR low ≤ RR <RR high	RR high (bpm)	40	20–40 34 for COPD & neurological disorders	20–40 34 for COPD & neurological disorders
V_T low ≤ V_T	V_t low	6 ml/kg	250 ml	300 ml
ET_{PCO_2} < ET_{PCO_2} high	ET_{PCO_2} (mmHg)	55	45–65 65 for COPD	45–65 65 for COPD
RR max (bpm)		50	36	36

IBW ideal body weight, *COPD* chronic obstructive pulmonary disease

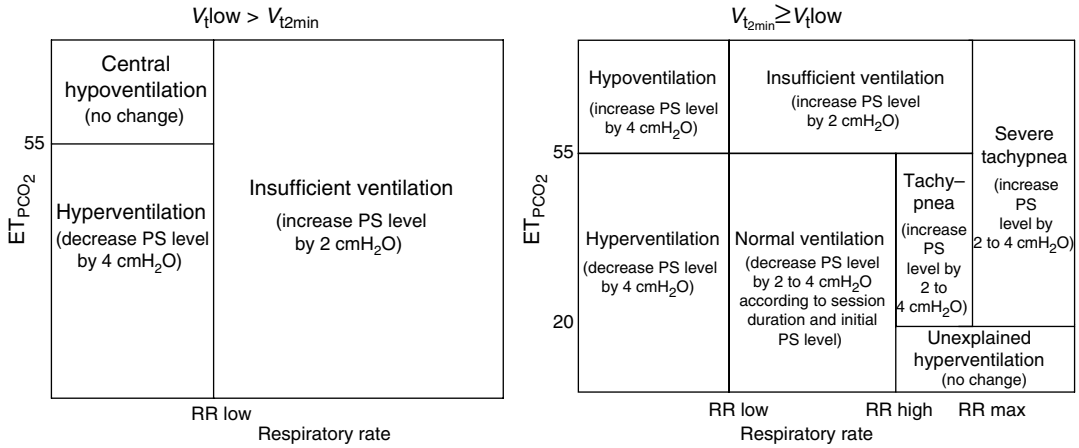

Fig. 61.2 Classification of ventilation by SmartCare/PS® Draeger Medical. Pressure support level is modified according to values of tidal values (below $V_t$low: panel **a**, above $V_t$low: panel **b**), respiratory rate and end-tidal PCO_2 at 2–5 min intervals (SmartCare waits 2 min for the next "Classification of Ventilation" if PS was not changed and waits 5 min if PS was changed (either by SmartCare or by the user))

61.2.1.2 Primary Goal: To Safely Maintain the Child in a Zone of Respiratory Comfort (Normal Ventilation)

In contrast to conventional ventilation modes, SmartCare/PS® continuously adapts the pressure support level to maintain normal ventilation. Normal ventilation corresponds to a respiratory pattern that is determined by lower and upper thresholds of tidal volume, respiratory rate and ET_{PCO_2} (Table 61.2). In turn, these thresholds are defined within acceptable limits as reported by a large panel of paediatric intensivists (Santschi et al. 2007). To keep the patient in normal ventilation, the pressure support level is increased or decreased according to the implemented rules of the knowledge base that represents the ECP (Fig. 61.2) (Mersmann 2009).

61.2.1.3 Weaning of Ventilatory Support

When the child remains in normal ventilation for a predefined period of time (60, 30 and finally 15 min), the PS level is gradually decreased (Jouvet et al. 2007), which is called a regular weaning step. During the entire execution of the ECP, duration of stability and duration of instabilities are balanced and taken into account when assessing the patient's needs. When the patient's respiratory pattern is outside the limits of normal ventilation, an instability is noted. A maximum of two instabilities will be tolerated by SmartCare/PS® before the pressure level will be increased.

61.2.1.4 Spontaneous Breathing Trial

An automated SBT is started if the patient is in normal ventilation at a predefined minimal

Table 61.3 Spontaneous breathing trial on SmartCare/PS® and IntelliVent®

	SmartCare/PS®	IntelliVent®
Criteria to start SBT:		
PIP (cmH_2O)	≤5[a], ≤7[b], ≤9[c] or ≤10[d]	0–50 (adjustable)
PEEP (cmH_2O)	≤5–15 (adjustable)	0–25 (adjustable)
FiO_2	≤0.3–1 (adjustable)	0.21–1 (adjustable)
Spontaneous ventilation	Patient with normal ventilation (Table 61.2)	Spontaneous breath percentage (adjustable between 0 and 100 %)
Others		RSB, variability index or $P_{0.1}$
SBT duration	1 h if initial PS level ≤22 cmH_2O	Adjustable
	2 h if initial PS level >22 cmH_2O	

SBT spontaneous breathing trial, *PS* pressure support, *RSB* rapid shallow breathing

[a]Patient >35 kg, tracheotomised with active or no humidification

[b]Patient >35 kg, endotracheally intubated with active or no humidification

[c]Patient >35 kg, tracheotomised, with heated/moisture exchange filter

[d]Patient ≤35 kg or >35 kg, endotracheally intubated, with heated/moisture exchange filter

pressure support level, PEEP level and FiO_2 below preset thresholds (Table 61.3). When the SBT is successfully passed, a message is displayed on the ventilator. Caregivers have to decide whether the patient may be extubated. If the patient is not extubated, SmartCare/PS® continues to be active trying to preserve the therapeutic success, and if the patient's spontaneous breathing may become unstable afterwards, SmartCare/PS® maintains or cancels the SBT successful message depending on the level of the instabilities.

61.2.2 SmartCare/PS® in Clinical Practice

Among the first 20 paediatric patients treated with SmartCare/PS®, median time in normal ventilation was 91 % (range, 0.7–99 %) (Jouvet et al. 2007). The median number of changes in the pressure support level over the entire study period was 1.5 changes per hour (range, 0.7–8.2). Variation of pressure support level was mostly due to low tidal volume and high respiratory rate (> 95 %), although a few changes were due to low respiratory rate or high ET_{PCO_2}.

We reported two clinical trials on SmartCare/PS® in children (Jouvet et al. 2007; Jouvet et al. 2010a). In the randomised clinical trial (RCT) at Sainte Justine Hospital–Montreal (Canada), a significant decrease in weaning duration in the SmartCare/PS® group ($n=15$) was observed when compared to usual care ($n=15$), without any modification in weaning failure rates (Jouvet et al. 2010a). These results need to be validated in a multicentre RCT especially because the positive impacts of SmartCare/PS® can vary from one PICU to another. This was observed in adult ICUs showing a real improvement in an European RCT (Lellouche et al. 2006) as well as no significant impact in a pilot RCT in Australia (Rose et al. 2008). The various impact of SmartCare/PS® across ICUs can be due, at least partially, to different organisation of mechanical ventilation. For example, in the pilot RCT in the adult Australian ICU, weaning in the study ICU was performed by experienced and relatively autonomous nurses, using a 1:1 nurse-to-patient ratio maintained over all shifts. This was not the case in the European centres.

The major strength of SmartCare/PS® is the implementation of an automated evidence-based ECP for mechanical ventilation with a user-friendly interface that allows individual customisation. According to Chatburn and Deem (2007), evidence-based ECPs provide many benefits like increased adherence to evidence-based interventions, reduced practice variability, improved outcomes, improved safety and enhanced education. There are several improvements to consider surrounding SmartCare/PS®: (1) step 1 of weaning is not included so far (Fig. 61.1). The need to switch to pressure support mode prior to consider SmartCare/PS® requires that caregivers have first to evaluate if the patient can breathe spontaneously. (2) Children with IBW below 15 kg are excluded. Therefore, another

ECP is needed in the same PICU for infants. (3) PEEP and FiO_2 are not automatically adjusted by SmartCare/PS® but are recommended criteria to SBT initiation.

61.3 IntelliVent®: Hamilton Medical

IntelliVent® is an explicit computerised protocol for the automated control of minute volume, PEEP and FiO_2 in adaptive support ventilation (ASV). IntelliVent® manages, with (open loop) or without the need of caregiver's intervention (closed loop), the four following weaning steps: (1) switch from control ventilation to spontaneous breathing (specificity of ASV mode; see chapter on ASV); (2) automatic adaptation of the pressure to maintain the patient in a range of respiratory rate, ET_{PCO_2} and SpO_2; (3) an automated SBT when children reach a minimum ventilatory support; and 4) a timer that shows SBT duration (Table 61.1). IntelliVent® is only available on new generation of Hamilton Medical ventilators (Hamilton S1) that continuously monitor usual mechanical ventilation parameters plus ET_{PCO_2} and SpO_2.

61.3.1 Description of IntelliVent®

IntelliVent® has two automated adjustment features: one is the automatic minute volume adjustment (CO_2 controller), the other one is the automatic FiO_2 and/or PEEP adjustment (O_2 controller). These two controllers can be set to manual or automatic. In manual mode, the controllers displayed a recommendation for the adjustment of minute ventilation, FiO_2 or PEEP (open loop). In automatic mode, the adjustments of minute ventilation, FiO_2 and/or PEEP are instantaneously corrected (closed loop). The CO_2 and O_2 controllers can be activated separately.

61.3.1.1 IntelliVent® (CO_2 and O_2 controllers) Start Criteria

IntelliVent® can be activated as soon as the patient is ventilated in ASV mode. This explicit computerised protocol is designed to manage the ventilator course of children with various diseases (ARDS, COPD, brain injury). In the lack of evidence of ventilatory support using IntelliVent® in the acute phase in paediatrics, we will focus this section on the management of the weaning phase.

IntelliVent® can be prescribed when a child, with IBW ≥7 kg, fulfils readiness to wean criteria that were used in a prospective clinical trial (NCT01095406) (Jouvet et al. 2010b). These weaning criteria are the same criteria used for Smartcare/PS®. In addition, it is recommended to validate that ET_{PCO_2} is correlated to blood gas PCO_2 (gap between ET_{PCO_2} and PCO_2 ≤7 mmHg on last blood gas). Pressure support test is not an obligation as assisted breath (pressure support) is given to the patient as soon as the patient is able to trigger the breath (see section 8.1.3.3.3 on Adaptive Support Ventilation).

61.3.1.2 CO_2 Controller

Primary goal of CO_2 controller: to adjust minute volume to patient needs.

ASV uses a pressure-controlled, synchronised time-cycled breathing pattern and maintains operator preset minimum minute for ventilation independent of the patient's spontaneous breathing activity. Minute volume is based on IBW calculated from the body height. The target breathing pattern (tidal volume and respiratory rate) is calculated using Otis' equation (Otis et al. 1950), based on the assumption that the optimal breathing pattern results in the least work of breathing. In addition, a lung protection strategy ensures permissive hypercapnia in the acute phase.

The CO_2 controller aims to increase or decrease minute volume with a maximum change of 1 % minute volume per breath. The modification of minute volume is different when the patient is breathing spontaneously (patient active) or not (patient passive). The patient is considered passive if there are more than three consecutive mechanical breaths without any patient effort. The patient is considered active when three to five consecutive mechanical breaths are triggered by the patient's own inspiratory effort.

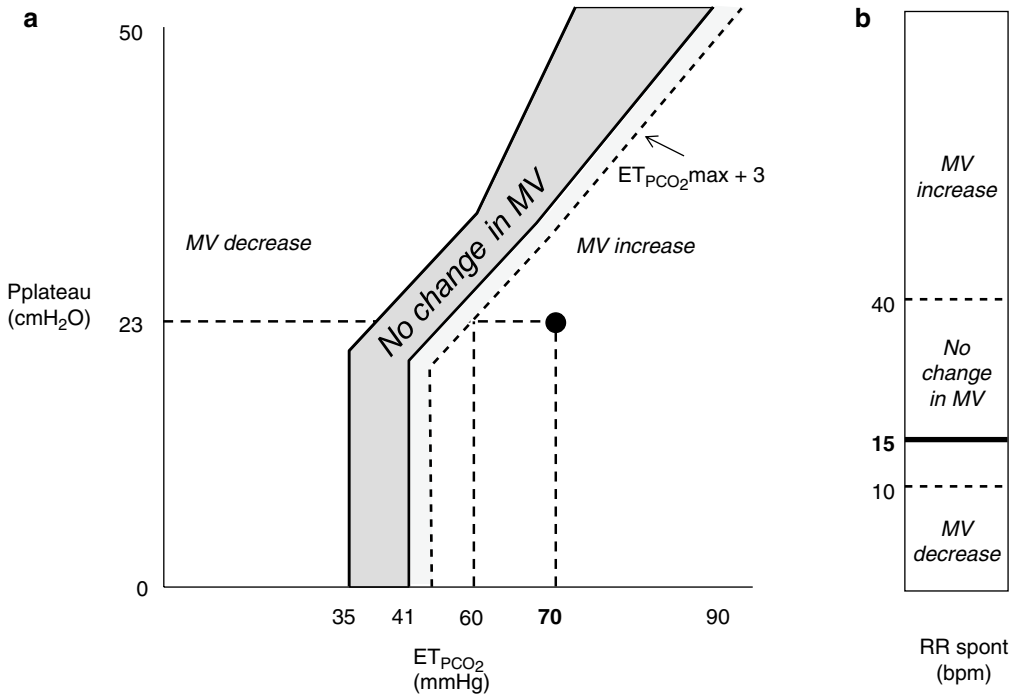

Fig. 61.3 CO_2 controller algorithm to modify minute volume (*MV*) according to end-tidal PCO_2 (ET_{PCO_2}) in patients without any respiratory efforts (panel **a**) and in patients with respiratory efforts (panel **b**). In addition, if spontaneous respiratory rate is within the optimal range but $ET_{PCO_2} > ET_{PCO_2}$ maximum + 3 mmHg (see threshold in panel **a**), MV will also been increased. Two examples: (1) a patient without any spontaneous breath, with a plateau pressure of 23 cmH_2O and ET_{PCO_2} of 70 mmHg will have an increase of minute volume by 1 % of MV per breath until the ET_{PCO_2} will be in the grey area ("no change of MV") unless the increase of plateau pressure or minute volume reach upper ventilator alarm limits. (2) A patient breaths spontaneously at 15 spontaneous breaths per minute and plateau pressure is 23 cmH_2O; he will have an increase of minute volume by 1 % of MV per breath if ET_{PCO_2} is above 60 mmHg (see panel **a**). MV will increase until the ET_{PCO_2} will be in the grey area of panel **a** ("no change of MV")

- Patient passive: When there is no spontaneous breath, the CO_2 controller increase or decrease minute volume in order to maintain ET_{PCO_2} in an optimal range. A permissive hypercapnia ventilation is implemented resulting in increase and larger optimal ET_{PCO_2} range when plateau pressure increases (Fig. 61.3 panel a).
- Patient active: When the patient is breathing spontaneously, minute volume is mainly adjusted to maintain respiratory rate within optimal range according to spontaneous respiratory rate (see Fig. 61.3 panel b). In addition, if spontaneous respiratory rate is within the optimal range but $ET_{PCO_2} > ET_{PCO_2}$ maximum + 3 mmHg (Fig. 61.3 panel a), then the CO_2 controller increases minute volume until $ET_{PCO_2} \leq ET_{PCO_2}$ maximum.

61.3.1.2.1 Decrease of Ventilatory Support

The CO_2 controller adapts minute volume to patient's needs and positive pressure is decreased according to improvements in lung mechanics.

61.3.1.2.2 Spontaneous Breathing Trial

Caregivers can set several criteria for SBT start, including FiO_2, PEEP, MV, PIP above PEEP, spontaneous breath percentage (average of the percentage of spontaneous breaths over the last 8 total breaths) and eventually one of the three following weaning indexes: rapid shallow breathing, variability index or $P_{0.1}$. When these criteria are all fulfilled, an SBT timer starts. Caregivers also have to define the SBT duration before considering separation from the

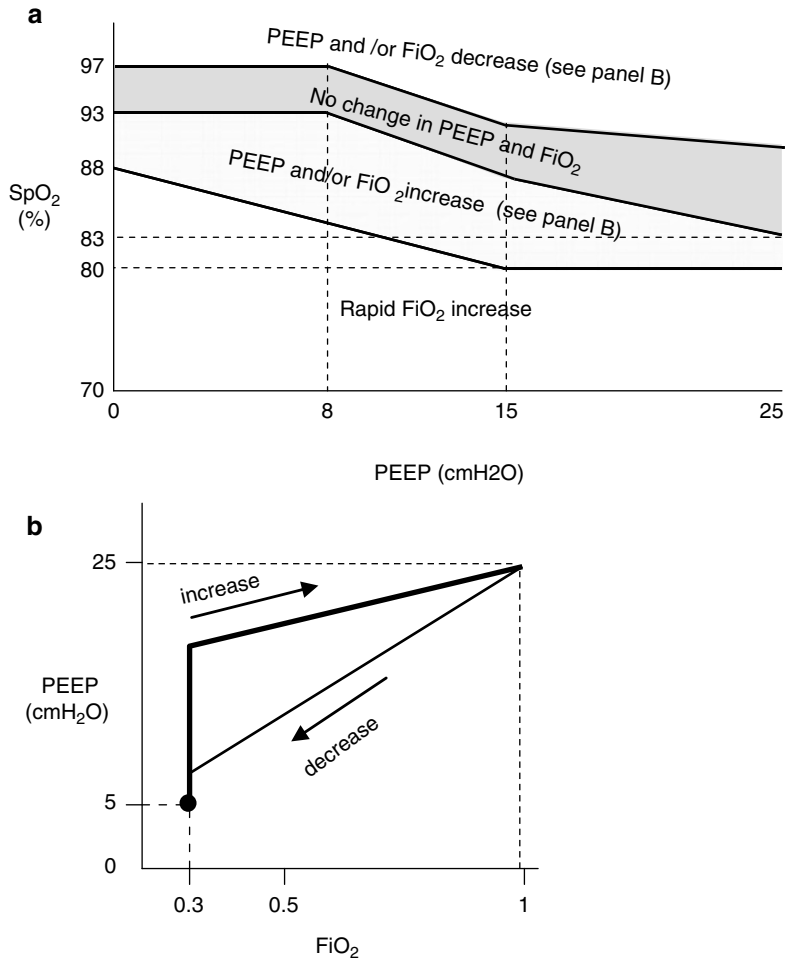

Fig. 61.4 O_2 controller algorithm to modify PEEP and FiO_2 according to actual SpO_2. Panel **a**: thresholds of SpO_2 to increase or decrease PEEP and/or FiO_2. A specific algorithm increases rapidly FiO_2 when SpO_2 is below a minimum threshold. Panel **b**: the algorithm used to modify PEEP and FiO_2 is shown. The algorithm on PEEP/FiO_2 adjustments is a mixture of the ARDS network protocol (The Acute Respiratory Distress Syndrome Network 2000) and the higher PEEP algorithm after protocol changed scales (Brower et al. 2004). Caregivers can activate only FiO_2 or only PEEP or both PEEP and FiO_2 adjustments

ventilator. Further research is needed to validate SBT criteria.

61.3.1.3 O_2 Controller

Primary goal of O_2 controller: *to adjust PEEP and/or FiO_2 to actual SpO_2*, PEEP and FiO_2 can be automatically adjusted according to the SpO_2. The O_2 controller consists of two separate adjustments:

- A rapid response FiO_2 adjustment that controls FiO_2 on a breath-by-breath interval. The rapid response FiO_2 sets FiO_2 to 1 as soon as SpO_2 is below the lowest acceptable value (Fig. 61.4 panel a).
- A regular PEEP and/or FiO_2 adjustment which controls PEEP and FiO_2 using a longer control interval. In the regular PEEP/FiO_2 adjustment, the algorithms used to modify PEEP and FiO_2 are shown in Fig. 61.4. Caregivers can choose only FiO_2, only PEEP or both PEEP/FiO_2 automatic adjustments. In addition to PEEP increase, automatic recruitment manoeuvre, applying pressure of 40 cmH_2O for 20 s, can also be activated.

61.3.1.3.1 PEEP Thresholds

PEEP can automatically decrease to 5 cmH_2O according to patient conditions. PEEP can also increase until an upper threshold is reached. This threshold can be set by users. In the absence of clinical experience, if automatic PEEP is activated, we recommend an upper PEEP threshold of 8 cmH_2O, in children.

The caregiver can also set the patient condition as "haemodynamic unstable" at O_2 controller

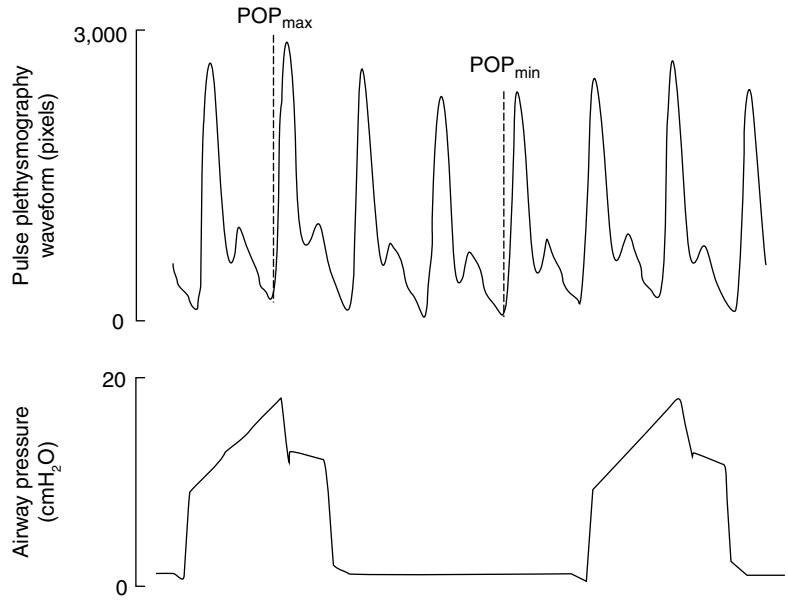

Fig. 61.5 Heart-Lung Index (HLI). HLI assesses the interaction between airway pressure and haemodynamics parameters as analysed by the pulse oximeter plethysmogram (POP). HLI is calculated as $HLI\ (\%) = (POP_{max} - POP_{min})/(POP_{max} + POP_{min}) * 100/2$

start. PEEP is then limited to 8 cmH_2O and no recruitment manoeuvre is performed.

During O_2 controller function, a heart lung interaction index (HLI) is also continuously monitored from the pulse oximeter (Fig. 61.5). The HLI reflects how much airway pressure interacts with haemodynamics. If HLI >15 %, it means high interaction. In such a case PEEP increase is limited, FiO_2 increase is preferred and no recruitment manoeuvre is performed. If no HLI value is available, a user message is given and PEEP is limited to 8 cmH_2O.

61.3.2 IntelliVent® in Clinical Practice

In adults, two clinical trials were conducted. Arnal et al. (2010) conducted a prospective randomised crossover controlled trial comparing ASV and Intellivent® in 43 adult patients with acute respiratory failure. In this trial, the patients ventilated with Intellivent® spent more time with optimal ventilation and had lower volumes and pressures for equivalent results on gas exchange. Lellouche et al. (2010) conducted a prospective randomised controlled study comparing usual care versus IntelliVent® in post cardiac surgery adult patients. The patients ventilated with Intellivent® spent also more time with optimal ventilation.

IntelliVent® has been assessed in one research trial on feasibility and safety in children. The preliminary report (Jouvet 2010) for the first 12 children included during the weaning phase concluded that (1) the CO_2 controller was adapted for children. ET_{PCO_2} monitoring was accurate. The specific medical diagnosis (ARDS, COPD, "push to wean") were helpful for ET_{PCO_2} thresholds adjustments which in addition can be further adjusted by ±5 mmHg. The development of an additional algorithm that tests the ability of children to breathe alone can improve CO_2 controller efficacy to wean all patients. (2) The O_2 controller manages FiO_2 adequately according to SpO_2 monitoring. PEEP-FiO_2 algorithm resulted in frequent modifications of PEEP that did not correspond to current clinical practice in paediatrics at Sainte Justine Hospital–Montreal (Canada). Therefore, PEEP management needs further study in children. (3) In the absence of Heart-Lung Index (HLI) assessment, the preset upper PEEP level at 8 cmH_2O at IntelliVent® start in children is recommended. (4) The use of IntelliVent® is not recommended in children with tracheal tube air-leak > 20 % (use of a cuffed tube is recommended) to ensure that minute volume prescribed is closed to minute volume delivered.

The major strength of IntelliVent® is the implementation of an automated ECP for mechanical

ventilation with a user-friendly interface that allows individual customisation of the whole ventilation course including CO_2 removal and O_2 delivery. Many components of this ECP are adjustable, and recruitment manoeuvres can be automated according to clinical practice in PICU. There are several improvements to consider surrounding IntelliVent®: (1) At present, there is not much clinical experience with this ECP. (2) Children with IBW below 7 kg are excluded. Therefore, another ECP is needed in the same PICU for younger children. (3) Automatic PEEP adjustment needs further research (see above). (4) Heart-Lung Index needs also further research to validate its use to limit PEEP increase.

Conclusions

The two explicit computerised protocols for weaning from mechanical ventilation are implemented by companies in one specific mode of ventilation (PSV or ASV). They either manage CO_2 removal settings (SmartCare/PS®) or both CO_2 removal and O_2 delivery settings (IntelliVent®). The main innovation of the two ECPs is the use of ET_{PCO_2} as a surrogate for blood gas PCO_2, to decrease or increase ventilatory support. This seems appropriate when the patient's own inspiratory effort trigger ventilatory support because the ECP assumes that the central respiratory command is able to set minute volume and ET_{PCO_2} is used to detect any failure in the respiratory command or muscle strength. When the patient is passive (no inspiratory effort), IntelliVent® is the only ECP available so far that is able to manage CO_2 removal. ET_{PCO_2} becomes a crucial input data for CO_2 removal. Paediatric caregivers are not routinely used to manage mechanical ventilation according to ET_{PCO_2} levels, and further research is mandatory to validate this point.

One of these ECP opened also a new area in the management of O_2 delivery. IntelliVent® adapts FiO_2 and PEEP according to SpO_2. In clinical practice, SpO_2 is nowadays a key input data to manage FiO_2 and specific recommendations for the simultaneous management of PEEP and FiO_2 have been published by the ARDS network and other research teams (The Acute Respiratory Distress Syndrome Network 2000; Brower et al. 2004). Then, an ECP that manages both PEEP and FiO_2 according to SpO_2 is logical. In clinical practice, several other factors also influence the prescription of PEEP including haemodynamic state and regional distribution of ventilation (on chest X-ray or tomodensitometry). To take into account these factors, IntelliVent® has specific surrogates for these factors, including patient condition prescription (e.g. "ARDS patient", "brain injury", "haemodynamic unstable") and HLI (surrogate of haemodynamic instability). Further research in children is needed to validate their use.

The large amount of information collected in this book demonstrates that we now need to synthesise our knowledge. Explicit computerised protocols are one way to synthesise and standardise care in mechanical ventilation with individual customisation. The two ECP described here are the innovators. Further research is needed to better assess the efficacy and tolerance of these two ECPs in children and to develop ECP that are dedicated to all ages including neonates.

Essential Point

SmartCare/PS® and IntelliVent® are new explicit computerised protocols that need further research in children.

References

Arnal J, Wysocki M, Demory D, Durish G, Laubscher T, Novotni D et al (2010) Prospective randomized crossover controlled study comparing adaptive support ventilation (ASV) and a fully close loop control solution (Intellivent®) in adult ICU patients with acute respiratory failure. Am J Respir Crit Care Med 181:A3004 (abstract)

Boles JM, Bion J, Connors A, Herridge M, Marsh B, Melot C et al (2007) Weaning from mechanical ventilation. Eur Respir J 29(5):1033–1056

Brower RG, Lanken PN, MacIntyre N, Matthay MA, Morris A, Ancukiewicz M et al (2004) Higher versus lower positive end-expiratory pressures in patients

with the acute respiratory distress syndrome. N Engl J Med 351(4):327–336

Chatburn RL, Deem S (2007) Respiratory controversies in the critical care setting. Should weaning protocols be used with all patients who receive mechanical ventilation? Respir Care 52(5):609–619

Jouvet P (2010) Report on IntelliVent – Hamilton medical in children. Sainte-Justine Hospital, Montreal, 11 pages

Jouvet P, Farges C, Hatzakis G, Monir A, Lesage F, Dupic L et al (2007) Weaning children from mechanical ventilation with a computer-driven system (closed-loop protocol): a pilot study. Pediatr Crit Care Med 8:425–432

Jouvet P, Payen V, Gauvin F, Santschi M, Eddington A, Lacroix J (2010a) Weaning children from mechanical ventilation with a computer-driven explicit protocol: a randomized clinical trial. Am J Respir Crit Care Med 181:A3899 (abstract)

Jouvet P, Wysocki M, Emeriaud G (2010b) Safety and feasibility study of a mechanical ventilation computerized protocol: Intellivent (CloserPed): www.ClinicalTrials.gov, NCT01095406

Lellouche F, Mancebo J, Jolliet P, Roeseler J, Schortgen F, Dojat M et al (2006) A multicenter randomized trial of computer-driven protocolized weaning from mechanical ventilation. Am J Respir Crit Care Med 174(8):894–900

Lellouche F, Bouchard P, Wysocki M, Laubscher T, Novotni D, Lopez R et al (2010) Prospective randomized controlled study comparing conventional ventilation versus a fully closed-loop ventilation (IntelliVent®) in post cardiac surgery ICU patients. Am J Respir Crit Care Med 181:A6035 (abstract)

Mersmann S (ed) (2009) Instruction for use of SmartCare/PS SW 2.n. Draeger Medical, Luebeck

Otis AB, Fenn WO, Rahn H (1950) Mechanics of breathing in man. J Appl Physiol 2(11):592–607

Rose L, Presneill JJ, Johnston L, Cade JF (2008) A randomised, controlled trial of conventional versus automated weaning from mechanical ventilation using SmartCare/PS. Intensive Care Med 34(10):1788–1795

Santschi M, Gauvin F, Hatzakis G, Lacroix J, Jouvet P (2007) Acceptable respiratory physiologic limits for children during weaning from mechanical ventilation. Intensive Care Med 33(2):319–325

Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network (2000) N Engl J Med 342(18):1301–1308