Ventilatory management of acute respiratory distress syndrome (ARDS) in adult patients and children (excluding neonates)

Société de Réanimation de Langue Française experts recommendations

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Introduction and presentation of the SRLF experts guideline methodology.

These guidelines have been formulated by a group of experts selected by the SRLF. These experts have established an evidence-based section of the topic submitted to them. On the basis of this section, each expert has selected the key ideas of the topic in order to formulate the guidelines and have submitted them to the group of experts. The objective was not to define a single consensual opinion of the experts on all of the proposals, but to clearly establish points of concordance, the basis for guidelines, and points of discordance or indecision, in order to propose a basis for further studies.

Each guideline was scored on a scale from 1 to 9 by each expert according to a methodology based on RAND/UCLA. Each participant answered questions using a graduated scale from 1 to 9 (1 corresponded to “complete disagreement” or “total absence of proof” or “formal contraindication” and 9 corresponded to “complete agreement” or “formal proof” or “formal indication”).

Three areas were subsequently defined in relation to the median:
• zone (1–3) corresponded to the zone of “disagreement”;
• zone (4–6) corresponded to the zone of “indecision”;
• zone (7–9) corresponded to the zone of “agreement”.

The agreement, disagreement, or indecision is considered “good” when the median interval was located in one of the three intervals [1–3] or [4–6] or [7–9].

Otherwise, agreement, disagreement or indecision is considered “poor” (e.g. interval ranging from [1–4] or [6–8]).

The guidelines proposed for the first nine fields of reference concerned adults and children (excluding neonates).
1. Field 1. Definitions and severity criteria of acute respiratory distress syndrome (ARDS)

1.1. The current definition of ARDS, established by an international consensus conference, should be maintained (poor agreement). It includes the following four points:

- acute respiratory failure (ARF), i.e. sudden or rapidly progressive onset,
- bilateral alveolar images on standard chest X-ray,
- PaO₂/FiO₂ ratio ≤ 200 mmHg, regardless of the level of positive end-expiratory pressure (PEEP) and the FiO₂,
- absence of signs of left atrial hypertension.

1.2. The following severity criteria should be taken into account during ARDS:

- age in adults (good agreement).
- presence of immune depression (good agreement).
- severity on admission assessed by the Simplified acute physiologic score in adults, and the Pediatric Risk of Mortality (PRISM) or Pediatric Index of Mortality (PIM) in children (good agreement).
- presence of circulatory failure with persistent metabolic acidosis despite correction of possible hypovolemia (good agreement).
- a PaO₂/FiO₂ ratio ≤ 150 mmHg (poor agreement).  

Poor agreement was only reached for the following points concerning the definition, severity, and cause of ARDS.

1.3. Due to the limits of the current definition, the concept of confirmed ARDS has been proposed, corresponding to patients initially presenting with international diagnostic criteria and who have maintained a PaO₂/FiO₂ ratio ≤ 200 mmHg after 24 h of mechanical ventilation (MV) with a PEEP ≥ 5 cmH₂O (poor agreement). 

Although this proposed definition is more precise and avoids classifying transiently hypoxemic patients as ARDS, it should be more extensively evaluated.

1.4. Murray’s “Lung Injury Severity Score” should be abandoned (poor agreement).

1.5. As regards ventilatory management, the distinction between pulmonary ARDS and extrapulmonary ARDS should be abandoned (poor agreement). Although the specific clinical management of these two types of disease have not been defined, some experts in fact consider that the approach to pulmonary ARDS should not be the same as that of extrapulmonary ARDS. Pathophysiological studies must therefore be conducted on this subject to more clearly distinguish these patients and the manner that they should be treated.

2. Field 2. Objectives of ventilatory management of ARDS based on pathophysiological and histological data

2.1. Oxygen toxicity

As regards this subject which is extremely important for clinical practice, the experts agreed that:

2.1.1. The toxicity of oxygen administered at high concentrations has not been demonstrated in humans (good agreement).

However, not all experts agree on the following points:

2.1.2. The pulmonary safety of pure O₂ in ARDS has not been demonstrated (poor agreement).

2.1.3. The use of high FiO₂ (> 80%) can promote the development of absorption atelectasis, particularly when it is associated with low PEEP (poor agreement).

2.2. Prevention of barotrauma and volutrauma

Proposals concerning this field of guidelines are based on a review of acquired knowledge derived from physiological studies and multicenter trials on ventilation of ARDS. A good agreement was reached for all of the following proposals. They were considered to have a significant impact on clinical practice and therefore constitute a basic prerequisite for optimal ventilatory management of ARDS.

2.2.1. It has been demonstrated that MV can increase pulmonary lesions and induce significant mortality due to excessive pressure (barotrauma) (good agreement), as well as excessive volumes (volutrauma) (good agreement).

2.2.2. The use of a tidal volume (Vt) ≥ 12 ml/kg of the predicted ideal body weight is associated with significant mortality increase (good agreement).

2.2.3. Limitation of Vt could reduce the incidence of barotraumatic and volutraumatic complications (good agreement).

2.2.4. Limitation of plateau pressure (Pplat) could reduce the incidence of barotrauma, particularly pneumothorax (good agreement).

2.2.5. One of the objectives of MV is to limit the risks of these complications by ensuring minimally traumatic ventilatory support prior to efficacy of specific treatment of the underlying disease responsible for ARDS (good agreement).

2.2.6. The prevention and recognition of these MV-related complications must therefore constitute a priority in the management of ARDS (good agreement).

2.2.7. So-called “permissive” hypercapnia does not represent an objective of treatment per se, but is a possible consequence of a ventilatory strategy designed to prevent barotraumatic and volutraumatic pulmonary lesions (good agreement).

2.2.8. With certain exceptions (intracranial hypertension, associated metabolic acidosis), correction of respiratory acidosis should not hinder the objectives of lung protection (good agreement). This guideline suggests, for example, that in
patients with hypercapnic acidosis, an increase of Vt is not justified when it induces an increase of Pplat above recommended values.

2.2.9. Administration of bicarbonate solution simply to correct isolated respiratory acidosis is not recommended (good agreement).

3. Field 3. Criteria of choice for ventilator and ventilation mode during ARDS

3.1. Choice of ventilator

3.1.1. It is recommended to use a ventilator which permits easy and reliable measurement of the following parameters: Vt, Pplat (by end-inspiratory occlusion), total PEEP (PEEPtot = PEEPset + intrinsic-PEEP) (by end-expiratory occlusion) (good agreement).

3.1.2. Furthermore, in adults this ventilator should permit correction of Vt measurement for compression of gases in the circuit or should be able to measure this volume using a proximal sensor (good agreement). This is a major guideline that is unfortunately too often neglected, as a considerable proportion of the Vt delivered by the inspiratory valve of the ventilator is compressed in the inspiratory circuit and is therefore not delivered to the patient. During expiration, the pressure drop in the airways is responsible for decompression in this loss of volume, which is consequently measured by the expiratory valve sensor. The displayed expired Vt is subsequently falsely reassuring for the clinician. Modern ventilators, which propose a test on start-up, are able to automatically compensate for this loss of Vt by an internal algorithm which depends on the peak pressure and compliance of the circuits. For example, a peak pressure of 60 cmH2O is responsible for compression of approximately 120 ml which must therefore be subtracted from the set Vt if the ventilator does not compensate for compliance of the circuit.

3.2. Choice of ventilatory mode

3.2.1. It is reasonable to recommend the use of thoroughly evaluated ventilatory modes that are well understood by clinicians (good agreement).

3.2.2. No ventilation mode has been formally demonstrated to be superior in terms of mortality or morbidity during MV of ARDS (good agreement).

3.2.3. In the absence of demonstrated benefit, ventilation with inversion of the I/E ratio should not be recommended (good agreement).

3.2.4. In the absence of sufficient clinical data, the demonstrated physiological advantages of the “BIPAP-APRV” mode (Biphasic Positive Airway Pressure Ventilation - Airway Pressure Release Ventilation) does not justify the use of this mode during ARDS (good agreement).

3.2.5. Due to their complexity and potential risk, the use of “dual-modes” (i.e. tidal volume-controlled pressure), also should not be recommended (poor agreement).

3.2.6. For constant total PEEP and Vt, the risks of overdistension and/or barotrauma are the same for pressure or volume ventilation modes (good agreement).

3.2.7. For constant total PEEP, Vt and inspiratory time, pressure or volume ventilation modes have the same effects on gas exchange and similar hemodynamic consequences (good agreement).

3.2.8. Despite the absence of differences between volume and pressure-controlled modes in terms of prognosis and morbidity, it is recommended to use volume modes during MV of ARDS to facilitate monitoring of Pplat (good agreement).

3.2.9. An end-inspiratory pause of 0.2–0.5 s allows regular repeated measurement of Pplat (good agreement).

3.2.10. Adjustment to a sufficiently high level of inspiratory flow (> 50 l/min for example in adults) is recommended (during the use of flow- or volume-regulated modes) as it contributes to reduce the patient’s work of breathing work and facilitates good patient-ventilator adaptation (good agreement). However, no form of inspiratory flow has specifically demonstrated its superiority (good agreement).

3.2.11. As regards constant Vt and respiratory rate, prolonging the inspiratory time, for example by means of a prolonged end-inspiratory occlusion, induces a significant reduction of dead space and PaCO2 (poor agreement).

3.2.12. In the absence of associated shock in patients with ARDS, pressure support ventilation (PSV) can be used, particularly at the initial stage of MV (poor agreement). This proposal offers interesting pathophysiological perspectives and warrants further studies.

3.2.13. In patients presenting spontaneous inspiratory activity and receiving assisted-controlled ventilation or PSV, assessment of the risk of overdistension and/or barotrauma is based on measurement of Vt. Monitoring of the expired Vt is recommended in these circumstances (good agreement). In this situation, the clinician may be misled by the PSV set pressure, while the presence of the patient’s spontaneous effort could be responsible for a very marked increase of transpulmonary pressure. This may be indicated by an increase of the Vt. Subsequently, this situation may theoretically increase the risk of volutrauma.

3.2.14. Any modification of ventilator settings must be followed by an evaluation of the physiological consequences of the new settings (respiratory rate, SaO2, Vt, Pplat, PEEPtot, transcutaneous pulse oximetry (SpO2), heart rate, blood pressure) (good agreement).

3.2.15. In each case, ventilator settings must be routinely re-evaluated at least twice a day (good agreement).

4. Field 4. Ventilator settings according to the mode ventilation used. Role of sedation/muscle relaxation and tracheal aspiration modalities

4.1. During MV of ARDS, the Vt and PEEP must be adjusted to guarantee the best compromise between prevention of lung distension, optimization of alveolar recruitment and adequate gas exchange (good agreement).
4.2. Tidal volume settings

4.2.1. In volume-controlled or assisted-controlled ventilation, the recommended Vt to be used during ARDS should be set between 5 and 10 ml/kg of the predicted ideal body weight (good agreement).

4.2.2. The mandatory limitation of pressure, particularly Pplat, that may lead to the use of a variable Vt from one patient to another, could be considered an accepted strategy during MV of ARDS (good agreement).

4.2.3. In general, Pplat must be maintained below or equal to 30 cmH2O (good agreement).

4.2.4. Pplat depends on both the Vt and PEEP settings (good agreement).

4.2.5. In some situations, a Pplat of 32–35 cmH2O could be accepted when chest wall compliance is very low (morbid obesity for example) (poor agreement). This proposal raises the problem of transpulmonary pressure, which could be “acceptable” despite a moderately high Pplat, as observed, for example, during the abdominal compartment syndrome. Further studies would therefore be useful in this context.

4.3. Increased respiratory rate and reduction of instrumental dead space

4.3.1. Two basic measures could be proposed to limit hypercapnia related to reduction of the Vt: reduction of instrumental dead space (good agreement) and increased respiratory rate (poor agreement).

4.3.2. Maximum reduction of instrumental dead space and PaCO2 can be achieved (only in deeply sedated patients without spontaneous breathing) by directly connecting the Y-piece to the proximal end of the endotracheal tube with insertion of a small internal volume connector to allow tracheal aspiration without disconnection (good agreement). This approach provides a modest reduction of PaCO2 and should not be applied in the absence of an endotracheal aspiration connector.

4.3.3. In the case of hypercapnic respiratory acidosis, it is recommended to use a heated humidifier rather than a heat and moister exchanger to reduce instrumental dead space (good agreement).

4.3.4. The efficacy of increased respiratory rate in terms of alveolar ventilation is more efficient when a smaller instrumental dead space is used (good agreement).

4.3.5. Increasing respiratory rate or decreasing expiratory time can be responsible for an increase in intrinsic PEEP (good agreement).

4.3.6. Once the Vt has been determined, the respiratory rate can be increased at a constant Ti/Ttot (i.e. by increasing the inspiratory flow rate and by shortening the inspiratory time) up to the limit of auto-PEEP (poor agreement).

4.4. PEEP settings

4.4.1. The minimal use of 5 cmH2O of PEEP, represents the basic ventilatory management of ARDS (good agreement).

4.4.2. Beneficial PEEP effects on oxygenation and recruitment should be balanced against the deleterious PEEP effects on hemodynamics and lung distension (good agreement).

4.4.3. PEEP increase should not be considered when it leads to an increase of Pplat above 30 cmH2O except in particular circumstances (good agreement).

4.4.4. When using high PEEP levels, a reduction of PEEP must be attempted daily, when possible (good agreement).

Poor agreement was only reached for the following proposals concerning PEEP settings, reflecting insufficient data and knowledge on this subject. Proposals concerning the value of chest X-ray to help in adjusting PEEP level offer interesting perspectives which warrant further clinical studies.

4.4.5. The harmful effects observed after increasing PEEP are even more significant as the Pplat increases (poor agreement).

4.4.6. The more severe the ARDS (at an early stage), the higher the PEEP level is required (> 10 cmH2O) (poor agreement).

4.4.7. PEEP levels greater than 20 cmH2O are only rarely useful in the ventilatory management of ARDS in adults (poor agreement).

4.4.8. It is not recommended to routinely adjust the PEEP level after any type of recruitment maneuver (poor agreement).

4.4.9. The chest X-ray characteristics can be useful to adjust PEEP (poor agreement).

4.4.10. Bilateral, diffuse opacities on the AP chest X-ray (“white lung” appearance) indicates high PEEP levels requirement (> 10 cm H2O) (poor agreement).

4.4.11. The persistence of considerable parenchymal aeration on the chest X-ray, particularly in the upper quadrants, suggests that PEEP levels should not exceed 10 cmH2O (poor agreement).

4.4.12. When the chest X-ray is used to adjust PEEP, this should be set at 5 cmH2O in order to limit errors of interpretation (taking into account the risk of desaturation) (indecision).

4.4.13. Chest CT scan can be useful to adjust PEEP, but is not recommended as a routine procedure (poor agreement).

4.5. FiO2 adjustment

4.5.1. During MV of ARDS, the FiO2 setting should attempt to achieve a target SaO2 greater than or equal to 88% (poor agreement), but remaining less than or equal to 96% (good agreement).

4.5.2. SaO2 is the parameter that should be used to assess oxygenation in routine practice (poor agreement).

4.5.3. The lowest FiO2 to achieve the defined target saturation is recommended, especially with low PEEP which could promote absorption atelectasis for high FiO2 (>80%) (good agreement).

4.5.4. Before any mobilization or manipulation (change, transport, tracheal aspiration, etc.) likely to cause desaturation, it is recommended to adjust the FiO2 in order to obtain a SaO2 greater than or equal to 98% (poor agreement).
4.6. Sedation/muscle paralysis

4.6.1. During MV of ARDS, the objectives of sedation are to ensure sufficient patient comfort while avoiding potentially dangerous patient-ventilator asynchrony (good agreement). These objectives must be achieved with the minimum effective level of sedation which must be checked regularly (several times a day, if necessary) (good agreement).
4.6.2. Sedation effectively decreases ventilatory requirements by reducing CO₂ production (good agreement).

The reduction of global oxygen consumption directly related to the reduction in respiratory muscle O₂ consumption can significantly improve the hemodynamic status of some patients. This effect should, therefore, not be overlooked.
4.6.3. As optimal sedation (minimum effective) may be sufficient, muscle paralysis must not be routinely performed during MV of ARDS (good agreement).
4.6.4. Muscle relaxation may be necessary, particularly during the initial phase of ARDS, to improve oxygenation or when sedation, considered to be optimal, or is considered to be insufficient to ensure good patient-ventilator adaptation (good agreement).
4.6.5. Muscle paralysis can also be used if it contribute to limiting Pplat to a value less than 30 cmH₂O, especially when neither PEEP nor Vt can be decreased (poor agreement).

4.7. Tracheal aspiration modalities

4.7.1. Tracheal aspiration can induce significant alveolar derecruitment that can sometimes be responsible for deep and prolonged desaturation (good agreement).
4.7.2. In order to limit this potentially harmful effect, it is recommended to perform tracheal aspiration without disconnecting the ventilator (good agreement) or ideally by means of a closed system (poor agreement).

5. Field 5. What monitoring tools can be used to ensure optimal ventilator settings and what is their place in ventilatory management?

5.1. Gas exchange

5.1.1. Arterial blood gas sample must be performed to adjust ventilatory settings during MV of ARDS (good agreement).
5.1.2. When arterial blood gas is required, it must be performed at least 15 min after any change of ventilator settings (good agreement).
5.1.3. Transcutaneous SpO₂ can be used to monitor SaO₂ with an accuracy of ±4%. SpO₂ use is strongly recommended during MV of ARDS (good agreement).
5.1.4. Continuous end-tidal CO₂ monitoring (PetCO₂) can provide useful information, but it is often difficult to interpret. Routine use of this technique should not be proposed (good agreement).

5.2. Classical respiratory mechanics parameters

5.2.1. Repeated examination of parameters and curves displayed on the ventilator is of major relevance to optimize ventilator settings (good agreement).
5.2.2. Peak pressure during constant-flow volumetric mode depends on variations of resistances, compliance and auto-PEEP (good agreement). For these reasons, peak pressure is a sensitive but not a sufficient alarm, to adjust ventilator settings (good agreement).
5.2.3. Pplat reflects end-inspiratory alveolar pressure and depends on the elastance of the respiratory system for a given Vt and total PEEP level. Pplat is therefore the most important parameter that should be monitored during ARDS MV (good agreement).
5.2.4. In volume-controlled or assisted-controlled ventilation, Pplat is the crucial parameter to assess the risk of overdistension (good agreement). Regular and repeated measurement of Pplat should be routinely performed in ARDS (good agreement).
5.2.5. In pressure-controlled ventilation, monitoring of expired Vt is essential for safety reasons and to detect modifications in the mechanical characteristics of the respiratory system (compliance, resistance) (good agreement).
5.2.6. In pressure-controlled or assisted-controlled ventilation, the inspiratory pressure can overestimate Pplat (good agreement).
5.2.7. End-expiratory occlusion is the method of choice to measure total PEEP (external PEEP + auto-PEEP) (good agreement).
5.2.8. The presence of auto-PEEP can be detected on the ventilator screen by the presence, on the flow–time curve, of an expiratory flow persisting at the end of expiration (good agreement). However, the absence of a persistent expiratory flow on the flow–time curve does not formally exclude the presence of auto-PEEP (good agreement).
5.2.9. It is, therefore, recommended to routinely measure total PEEP by an end-expiratory occlusion maneuver to more accurately evaluate the presence of auto-PEEP (good agreement).

However, procedures based on occlusion as discussed below (5.2.6. to 5.2.9) are not valid when the patient exhibits spontaneous respiratory muscle activity (assisted-controlled modes) (good agreement).
5.2.10. In volume-controlled or assisted-controlled modes, Pplat is difficult to interpret in cases of persistent spontaneous ventilatory activity (ventilator asynchrony) (good agreement).
5.2.11. Persistence of spontaneous respiratory muscle activity does not allow reliable use of end-expiratory occlusion to assess the presence of auto-PEEP (good agreement).

Some monitoring functions proposed by certain ventilators are of limited value and their use is therefore not recommended (good agreement).
5.2.12. Dynamic compliance measurement to adjust ventilator settings and/or to monitor patients, is limited due to
the influence of the resistive properties of the respiratory system. This procedure is therefore not recommended (good agreement).

5.2.13. The value of mean airway pressure measurement to adjust ventilator settings and/or for ventilatory surveillance during ARDS is limited and is therefore not recommended (good agreement).

5.2.14. The static compliance of the respiratory system (Vt/Pplat – total PEEP) can be useful to characterize the severity of the pulmonary disease and the time-course of ARDS (good agreement). However, on the basis of currently available data, the use of static compliance of the respiratory system cannot be recommended for the adjustment of PEEP (good agreement).

5.2.15. In constant-flow volume-controlled ventilation and in the absence of spontaneous breathing, the appearance of the pressure–time curve during inspiration (stress index) can be useful to evaluate the effect of Vt in terms of continuous recruitment (concave downwards) or alveolar overdistension (concave upwards) (poor agreement).

5.3. Static or quasi-static pressure–volume (P–V) curve

5.3.1. The P–V curve is difficult to interpret and its routine use is therefore not recommended in daily clinical practice (good agreement).

5.3.2. A quasi-static inspiratory P–V curve can be obtained at the patient’s bedside without any specific equipment. To achieve this goal, the ventilator should be able to generate a low constant-flow (< 9 l/min) with a screen able to display and capture volume and pressure signals to measure instantaneous values with a cursor (good agreement).

5.3.3. Intermittent measurement of the inspiratory P–V curve can be useful to assess the severity of the pulmonary disease, monitor the time-course of the disease and adapt ventilator settings to the respiratory mechanics of patients with ARDS (good agreement).

A number of limitations concerning the P–V curve must be emphasized.

5.3.4. Based on the current state of knowledge, when using the P–V curve, determination of the inferior inflection point appears to be of limited value to adjust the PEEP level (good agreement).

5.3.5. The lower inflection point can provide information regarding the distribution of pulmonary lesions and the effect of PEEP in terms of alveolar recruitment (poor agreement).

5.3.6. The slope or linear compliance of the inspiratory P–V curve is an indication of pulmonary disease severity and pulmonary recruitability and can be used to monitor alterations of respiratory mechanics during ARDS (poor agreement). Determination of this parameter is possible but cannot be recommended as a routine procedure to optimize PEEP settings (good agreement).

5.3.7. The upper inflection point is a marker of the end of recruitment and the start of alveolar hyperinflation. It could, therefore, indicate the end-inspiratory pressure that must not be exceeded during ventilation (poor agreement).

5.3.8. Estimation of intra-abdominal pressure, evaluated from measurement of bladder pressure, can be used to indirectly evaluate chest wall compliance and can therefore be useful to adapt ventilator settings to the mechanical constraints of the respiratory system (poor agreement).

5.3.9. Although this measurement is possible, the routine use of intra-abdominal pressure for monitoring of MV during ARDS cannot be recommended on the basis of the currently available data (good agreement).

5.4. Chest imaging

5.4.1. Chest X-ray is useful not only to verify invasive procedures (position of the endotracheal tube or catheters), but also to detect barotraumatic and volutraumatic complications related to MV (good agreement).

5.4.2. Routine chest CT scan cannot be recommended during the acute phase of ARDS because of the complexity of performing this procedure and the risk related to transport of an unstable patient (good agreement).

5.4.3. However, chest CT scan provides several useful insights regarding the type and severity of lung disease during ARDS (poor agreement).

5.4.4. Chest CT scan can also be used to monitor the course of pulmonary lesions during ARDS (poor agreement).

5.4.5. Chest CT scan can also be used to diagnose and quantify barotraumatic complications during ARDS (poor agreement).

5.4.6. Pleuropulmonary ultrasound can be useful for the detection and quantification of pleural effusion. On the basis of current data, it cannot be recommended to adapt MV or monitor complications of ARDS (good agreement).

6. Field 6. Place of non-invasive ventilation (NIV) and continuous positive airway pressure (CPAP)

6.1. CPAP should not be recommended in this indication (good agreement).

6.2. NIV is a high-risk and complex MV technique during ARDS (good agreement). For these reasons, NIV must only be performed by an experienced intensive care team. As, intubation may be required at any time (good agreement).

6.3. In hypoxemic ARF, the best results were observed in immunodepressed patients due to the high-risk related to intubation in these patients (good agreement).

6.4. NIV, used at an early stage in the course of ARDS, can reduce the intubation rate and improve the prognosis of selected patients (poor agreement).

6.5. Except in the context of immunodepressed patients, the persistence of ARDS criteria or the coexistence of another organ failure, particularly hemodynamic, intubation should be considered (good agreement). Similarly, the presence of repeated episodes of desaturation during NIV should indicate intubation (good agreement).

6.6. Despite the absence of clinical studies demonstrating an influence on the prognosis of patients, face mask should
be initially considered (good agreement). To improve patient tolerance, when NIV is prolonged, new interfaces such as a helmet or full face mask, should be considered (poor agreement).

6.7. Despite the absence of clinical studies demonstrating an influence regarding the prognosis of patients, humidification of inspired gases appears to be indicated during NIV, especially for cases of long duration (good agreement). On the basis of physiological evidence indicating the need not to increase inspiratory effort, active humidification (heated humidifier) should be preferred (poor agreement). However, this humidification may be unnecessary when using turbine ventilators with FiO2 less than 50% (poor agreement).

6.8. PSV with PEEP should be considered initially (poor agreement). The optimal modalities of PSV settings have not been clearly established in this indication. By comparison with physiological results obtained in other pathological situations, a PSV level of 8–15 cmH2O associated with a PEEP level of 5–10 cmH2O could be recommended (good agreement).

6.9. NIV during ARDS can improve safety (respiratory and hemodynamic) during invasive procedures such as bronchoscopy in more severely hypoxemic patients (poor agreement).

7. Field 7. Place of hemodynamic monitoring in the ventilatory management of ARDS

The following proposals concern hemodynamic instability which is often associated with ARDS. In contrast, ARDS which can be accompanied by septic shock, constitutes a specific problem, which is beyond the scope of these guidelines.

7.1. Hemodynamic monitoring

Hemodynamic monitoring plays a key role, as circulatory failure is often associated with respiratory failure during ARDS in adults (good agreement). Invasive arterial blood pressure monitoring is therefore essential in hemodynamically unstable patients (good agreement).

7.2. Echocardiography

7.2.1. Echocardiography, ideally transesophageal echocardiography, can detect the presence of acute cor pulmonale and a possible intracardiac shunt (good agreement). It can also detect causes of circulatory failure (poor agreement).

7.2.2. Cor pulmonale can be due to inadequate ventilatory management (good agreement). One of the major determinants of cor pulmonale is the level of Pplat (good agreement).

7.2.3. A high PEEP can also have harmful effects on the right ventricle (good agreement).

7.3. Pulmonary artery catheter

7.3.1. In a context of circulatory failure, hemodynamic monitoring can be performed by using a pulmonary artery catheter in adults and in children weighing more than 10 kg (poor agreement).

7.3.2. A pulmonary artery catheter can be used to diagnose most causes of acute circulatory failure (poor agreement).

7.3.3. The presence of pulmonary artery hypertension identified in the pulmonary artery catheter is not predictive of right ventricular tolerance (good agreement). Moreover, there is no definition of cor pulmonale based on pulmonary artery catheter measurements (poor agreement). However, it is suggested that there is a high probability of cor pulmonale when the central venous pressure is greater than the pulmonary capillary pressure (PCP) (good agreement).

Overall, only a poor agreement was reached concerning therapeutic strategies based on hemodynamic data, making it difficult to routinely recommend these procedures.

7.3.4. In hemodynamically stable and severely hypoxemic patients with documented ARDS, salt and water depletion may have a beneficial effect (poor agreement).

7.3.5. The pulmonary artery catheter can be used to guide salt and water depletion (poor agreement).

7.3.6. A PCP greater than 15 mmHg increases the risk of pulmonary edema. Reduction of the PCP, for example by the administration of diuretics, when compatible with hemodynamic stability and in the context of severe hypoxemia, should be considered (poor agreement). However, a strategy designed to maintain the lowest possible PCP must not be considered to be an objective per se and cannot be recommended (good agreement).

The following guidelines concern cor pulmonale. The importance of this phenomenon has now been suggested by several studies. Therapeutic approach proposed in the case of cor pulmonale is promising, but further studies are warranted to validate these guidelines.

7.3.7. The presence of cor pulmonale requires specific ventilatory measures designed to limit right ventricular afterload: reduction of Pplat (poor agreement); reduction of PEEP (poor agreement); limitation of respiratory acidosis (poor agreement).

7.3.8. The persistence of cor pulmonale associated with circulatory failure, despite adaptation of ventilation parameters to right ventricular function, indicates the need for inhaled NO (iNO) therapy for “hemodynamic” purposes (poor agreement).

7.3.9. The transpulmonary thermodilution technique (PiCCO® system) cannot be recommended for hemodynamic monitoring of patients ventilated for ARDS due to limits in the case of right ventricular failure in adults (poor agreement).

7.4. Arterial pulse pressure

7.4.1. In controlled ventilation, in a patient well adapted to the ventilator and in sinus rhythm, the variability of pulse pressure (APP) can predict the effect of an increased PEEP on cardiac output (poor agreement).
8. Field 8. Modalities and place of treatments and adjuvant

8.1. Recruitment maneuvers

8.1.1. On the basis of the current literature, routine use of recruitment maneuver cannot be recommended (good agreement). Furthermore, no data indicate the superiority of a particular technique in the various modalities available (high PEEP, prone positioning, sighing, sustained insufflation, etc.) (good agreement).

8.1.2. Recruitment maneuvers can induce harmful hemodynamic effects and/or overdistension (good agreement).

8.1.3. A recruitment maneuver could be applied during the acute phase of ARDS after episodes of derecruitment (tracheal aspiration) or accidental disconnection (poor agreement).

8.2. Prone positioning

8.2.1. Prone positioning cannot be routinely recommended in all ARDS patients (good agreement).

8.2.2. The indication for prone positioning could be considered in more severely ill hypoxemic patients (good agreement).

8.2.3. The optimal duration of prone positioning sessions remains to be determined. On the basis of currently available data, sessions lasting 6 to 12 h/24 h could be proposed (good agreement).

8.3. High-frequency oscillatory (HFO) ventilation

8.3.1. Clinical studies are not sufficient to recommend the use of HFO in first-line ventilatory management of ARDS (good agreement).

8.3.2. The available data in the literature suggest that HFO can improve gas exchanges during the acute phase of ARDS in some patients where gas exchange is insufficiently improved by conventional MV (poor agreement).

8.3.3. In the particular case of ARDS complicated by high-flow bronchopulmonary fistula, the use of HFO can be recommended in a specialized center (poor agreement).

8.4. Partial liquid ventilation

8.4.1. Despite promising experimental data, there is no clinical evidence to propose partial liquid ventilation in the ventilatory management of ARDS (good agreement).

8.5. Extracorporeal circulation techniques

8.5.1. Extracorporeal gas exchange techniques [(Extracorporeal membrane oxygenation (ECMO) and extracorporeal CO₂ removal (ECCO₂R)] can be useful in the case of failure of conventional MV. However, in view of their high cost, their invasive nature, and the risk of severe hemorrhagic and infectious complications, they must be reserved to clinical research protocols or in exceptional cases of hypoxemia refractory to all other treatments (poor agreement).

8.6. Lavage of instrumental dead space

8.6.1. Lavage of respiratory anatomical dead space by intratracheal insufflation of gas is confined to clinical research and cannot be routinely proposed to patients with ARDS (good agreement).

8.7. Inhaled nitric oxide (iNO)

8.7.1. iNO transiently improves oxygenation in some patients with ARDS, pulmonary hypertension and persistent hypoxemia despite conventional MV (good agreement).

8.7.2. However, the routine use of iNO during ARDS cannot be recommended on the basis of randomized prospective studies (good agreement).

8.7.3. iNO can be useful for the treatment of right ventricular failure or to facilitate closure of a patent foramen ovale, which accentuates hypoxemia by right-left shunt during ARDS (poor agreement).

8.7.4. The optimal dosage of iNO generally ranges between 0.5 and 5 ppm (mean dosage: 2 ppm) to observe an effect on oxygenation (good agreement). If iNO is used, the response to iNO must be evaluated individually and repeatedly (good agreement).

8.7.5. iNO therapy can be stopped abruptly due to the low risk of rebound effect (poor agreement).

8.7.6. Severe thrombocytopenia, intracranial hemorrhage and hemorrhagic syndromes are relative contraindications to iNO (good agreement).

8.8. Almitrine

8.8.1. The routine use of almitrine during ARDS is not recommended (good agreement).

8.8.2. The optimal dosage of almitrine must be evaluated on a case to case basis and ranges between 2 and 4 µg/kg per min (good agreement).

8.8.3. Almitrine must not be administered in cases of right ventricular dysfunction or failure, liver failure or lactic acidosis (poor agreement).

8.9. Surfactant

8.9.1. Despite encouraging experimental data, there is currently no clinical justification to propose surfactant in the ventilatory management of ARDS (good agreement).

8.10. Prostaglandins (PGE1, PG12)

8.10.1. The use of prostaglandin E1 (PGE₁) or inhaled prostacyclin (PGI₂) must be limited to clinical research protocols and is therefore not recommended in routine clinical practice (good agreement).
9. Field 9. ARDS complications and sequelae: what are they and how can they be prevented?

9.1. Barotrauma and volutrauma

9.1.1. Barotraumatic and volutraumatic lesions during ARDS can remain purely histological and may not be detected on chest X-ray or chest CT scan (good agreement).

9.2. Corticosteroids

9.2.1. Corticosteroids are not recommended in the acute phase of ARDS except in specific situations (pneumocystosis, eosinophil pneumonia, etc.) (good agreement).

9.2.2. At the present time, routine use of corticosteroids after the seventh day of non-resolving ARDS cannot be recommended, even after rigorously excluding the presence of infection (poor agreement).

9.2.3. With the exception of particular indications for corticosteroid therapy (pneumocystosis, eosinophil pneumonia, etc.), it is recommended to avoid, when possible, the combination of muscle paralysis and corticosteroids (good agreement).

9.3. Pulmonary fibrosis

9.3.1. Corticosteroid therapy is only indicated after histological confirmation of fibrous proliferation (poor agreement).

9.3.2. A formal histological diagnosis can only be obtained from surgical lung biopsy (good agreement).

9.3.3. Lung biopsy can provide useful diagnostic information during ARDS. However, it should only be performed in cases of non-resolving ARDS or in the case of diagnostic uncertainties that could lead to specific treatment (poor agreement).

9.4. Sequelae of ARDS

9.4.1. Pulmonary function tests (spirometry, 6-min walking test, etc.) can be useful to monitor the course of long-term sequelae of ARDS (good agreement).

9.4.2. Chest X-ray and especially chest CT scan can be used to monitor the long-term course of severe or complicated ARDS (poor agreement).

9.4.3. The presence of sequelae, particularly neuromuscular sequelae, must be investigated after resolution of ARDS in the case of persistent functional handicap (good agreement).

9.4.4. These sequelae could have a considerable impact on the patient’s return to work and social life (good agreement).

10. Field 10. Specificities of ventilatory management and monitoring during ARDS in children (excluding neonates)

10.1. Definitions and severity criteria of ARDS

10.1.1. Apart from the PaO2/FiO2 ratio, no other score (Oxygenation Index, Ventilation Index, adapted Lung Injury Score) should be recommended for either the diagnosis or evaluation of the severity of ARDS (good agreement).

10.1.2. During respiratory syncytial virus epidemics, RSV infection can be responsible for initial clinical features of ARDS, but the diagnosis can be corrected by reviewing the clinical and radiological signs 24 h later (good agreement).

10.2. Objectives of the ventilatory management of ARDS based on pathophysiological and histological data

10.2.1. Whenever possible, the FiO2 must be kept below 60% in infants under the age of 2 years, due to incomplete alveolar development (good agreement).

10.2.2. At the present time, routine use of corticosteroids (pneumocystosis, eosinophil pneumonia, etc.) should be reserved for infants weighing less than 5 kg (good agreement).

10.2.3. Continuous flow time-cycled ventilators (pressure limited) should be reserved for infants weighing less than 5 kg (good agreement).

10.3. Criteria of choice of ventilator and ventilation mode during ARDS

10.3.1. The use of a ventilator correcting Vt measurement for gas compression in the circuit or measuring this volume by means of a proximal sensor is strongly recommended in children (good agreement).

10.3.2. It is recommended to use a ventilator measuring insufflation pressures and effective flows by means of a proximal sensor on the Y-piece (tidal volume is obtained by integration of the flow curve) (good agreement).

10.3.3. The use of a cuffed endotracheal tube is recommended to eliminate tracheal leaks, but the inflation pressure must be monitored (good agreement).

10.4. Ventilator settings according to the mode of ventilation used

10.4.1. In assisted-controlled mode, the respiratory rate must be adjusted by taking into account the child’s age and can be modulated as follows, as a guide: 30–40 cycles per min (<1 year); 20–30 cycles per min (1–5 years); 15–25 cycles per min (>5 years) (good agreement).

10.5. What monitoring tools can be used to ensure optimal ventilator settings and what is their role in ventilatory surveillance?

There are no particular characteristics specific to children.

10.6. Place of NIV and CPAP

10.6.1. NIV should only be used in children by ICU teams familiar with this technique and when a range of adapted interfaces is available (good agreement).

10.6.2. NIV is not recommended as first-line treatment in ARDS in immunocompetent children (good agreement).

10.7. Place of hemodynamic monitoring in the ventilatory management of ARDS

10.7.1. Identification of cardiac or circulatory failure is crucial during the management of ARDS in children (good agreement).
10.7.2. Circulatory failure in children is defined as systolic blood pressure:
- < 65 mmHg for infants under the age of 1 month, despite adequate volume expansion (good agreement).
- < 70 mmHg for infants under the age of 2 years, despite adequate volume expansion (good agreement).
- < 80 mmHg for children under the age of 10 years, despite adequate volume expansion (good agreement).
- < 90 mmHg for children over the age of 10 years, despite adequate volume expansion (good agreement).

10.7.3. It is recommended to perform echocardiography during the first 24 h of management of ARDS in children (poor agreement).

10.7.4. In the presence of circulatory failure, hemodynamic monitoring by pulmonary artery catheter can only be considered in children weighing more than 10 kg (good agreement).

10.7.5. Transpulmonary thermodilution (PiCCO® system) can be useful to guide volume expansion and to monitor cardiac output in children in circulatory failure (poor agreement).

10.8. Modalities and place of treatments and adjuvant techniques during ARDS

10.8.1. The routine use of surfactant by intratracheal instillation cannot be recommended in children with ARDS (good agreement).

10.8.2. Surfactant has no impact on the prognosis, but can transiently improve oxygenation in most severely affected hypoxemic children (good agreement).

10.8.3. Due to its high cost, administration of surfactant must be exclusively reserved to cases of refractory hypoxemia, after failure of other adjuvant techniques (prone positioning or HFO ventilation) (good agreement).

10.9. Complications and sequelae of ARDS: what are they and how can they be prevented?

There are no specific pediatric requirements.