REVIEW ARTICLE

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Alveolar recruitment maneuver in mechanic ventilation pediatric intensive care unit children

A manobra de recrutamento alveolar em crianças submetidas à ventilação mecânica em unidade de terapia intensiva pediátrica

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ABSTRACT

Recent changes were introduced in acute hypoxemic respiratory failure children ventilation methods. There are evidences that less aggressive ventilation strategies can improve severe pulmonary injury patients' survival. Experimental trials evidenced a relationship between inappropriate ventilatory measures and delayed acute pulmonary injury improvement, or even worsening. From this, a protective ventilatory measure arises in combination with alveolar recruitment maneuver. This association is believed in clinical practice to determine importantly reduced morbidity and mortality as well as reduced mechanic ventilation-induced injuries. It is indicated for acute lung injury patients, generally from pneumonia or sepsis, with severe hypoxemia. Its main contraindications are homodynamic instability, pneumothorax and intracranial hypertension. Experimental trials showed beneficial maneuver effects on both oxygenation and alveolar collapse. Adult studies showed improved pulmonary function with hypoxemia reversion. In children, the maneuver lead to significant inspired oxygen fraction and alveolar collapse reductions, less oxygen dependency, improved pulmonary complacency, and reduced bronchopulmonary dysplasia. However, studies in children are limited. Additional investigation is warranted on this matter, and its clinical application evidence. A literature review was conducted based on textbooks and MEDLINE, Pubmed, Cochrane library, SciELO, and Ovid databases, from 1998 to 2009, both in Portuguese and English. Publications on alveolar recruitment maneuver both in adults and children, review articles, experimental and clinical trials were included using the key words: protective ventilatory strategy, alveolar recruitment maneuver, pediatrics and mechanic ventilation.

Keywords: Intensive care units; Respiration, artificial/adverse effects; Respiratory mechanics; Child

INTRODUCTION

Mechanic ventilation (MV) is considered a valuable tool to treat respiratory failure and decrease mortality in critically ill patients. Recent changes were introduced regarding how acute hypoxemic respiratory failure children are ventilated. However, experimental trials evidenced a relationship between inappropriate ventilatory measures and delayed improvement or even worsening of acute lung injury (ALI).(1-3) Additionally, clinical trials showed that less aggressive ventilatory strategies improve survival.(4,5)

In the eighties, the protective ventilation concept was introduced, aiming to both promote appropriate gas exchange and protect lung tissue integrity.(1,6) In the next decade, Lachmann(7) suggested “the open lung concept”, i.e., opening and keeping lungs open during mechanic ventilation. For this the alveolar recruitment maneuver (ARM) was used to open alveolar units by means of increased trans-pulmonary pressure. From this, a combined ventilatory strategy was created combining alveolar recruitment maneuver, low tidal volume and increased positive end expiratory pressure (PEEP).(8)

Alveolar recruitment maneuver has been used longer than two decades in severe lung injury MV patients. Its most important physiological consequence is improved lung injury patient’s oxygenation. The procedure should generally be followed by PEEP levels adjustment, with a fundamental role on efficacy maintenance.(4,7,9) These strategies are believed in clinical practice to determine importantly reduced morbidity and mortality. In addition, they can prevent MV-induced injuries, currently known as biotrauma, volutrauma and atelectrauma.(4,5,9-11)

ARM indication can be based on oxygen markers, as arterial oxygen pressure (PaO_2), PaO_2/inspired oxygen fraction rate (FiO_2), oxygenation index (OI), pulse oxymetry (SpO_2) and the SpO_2/FiO_2 ratio.(12,13) The quantification of lung injury degree is generally made using lung injury markers as Murray’s(14) acute lung injury score (LIS) and the static and dynamic pulmonary complacency. These markers, in association with computed tomography and electric bioimpedance, may prove and clarify pulmonary recruitment effects.(15,16) Normal oxygenation parameters values and the OI equation are listed on chart 1.(17) The acute lung injury score (LIS), modified for children, is shown on chart 2.

A literature review was made based on textbooks and the databases MEDLINE, Pubmed, Cochrane library, SciELO and Ovid from 1998 to 2009, both in Portuguese and English. Review articles, experimental and clinical trials both in adult and children, using the key words: protective ventilatory strategy, alveolar recruitment maneuver, pediatrics and mechanic ventilation were included. This study aimed to review the current concepts in alveolar recruitment maneuver, and to identify ARM indications, techniques, possible benefits and adverse effects, as well the cautions for its use in intensive care unit mechanic ventilation children.

Chart 1 - Normal oxygenation parameters range.(12,13,14,17)

Parameter	Normal range
PaO_2	
01 - 11months	85 ± 4 (mmHg)
01 - 09 years	90 ± 5 (mmHg)
10 - 19 years	96 ± 2 (mmHg)
PaO_2/FiO_2 ratio	> 300
Oxygenation index*	< 12%
Pulse oxymetry	88 - 95%
Sat O_2/ FiO_2	>315

according to the formula - (MAP X FiO_2/PaO_2) X 100. PaO_2 – arterial oxygen pressure; MAP – mean airways pressure; $SatO_2$ - pulse oxymetry.

Chart 2 - Lung injury score (Murray score) modified for children(14)

1. Chest X-ray	Score
No alveolar consolidation	0
1 quadrant alveolar consolidation	1
2 quadrants alveolar consolidation	2
3 quadrants alveolar consolidation	3
4 quadrants alveolar consolidation	4
2. Hypoxemia score: PaO_2/FiO_2	Score
>300	0
225-299	1
175-224	2
100-174	3
<100	4
3. PEEP score (under MV) (cmH_2O)	Score
< 5	0
5-6	1
7-8	2
9-11	3
>12	4
4.Static specific complacency ($ml/cmH_2O/kg$)	Score
>0.85	0
0.75-0.84	1
0.55-0.74	2
0.30-0.54	3
<0.30	4

Score calculation: sum of all components points divided by the number of components used

Final score:

No lung injury	Moderate lung injury	Severe lung injury (ARDS)
-	0.1 – 2.5	> 2.5

PaO_2 – arterial oxygen pressure; FiO_2 – inspired oxygen fraction; PEEP – positive end-expiratory pressure; MV – mechanic ventilation; ARDS – acute respiratory distress syndrome.

CAUSES OF ACUTE LUNG INJURY (ALI)

Several clinical disorders are known as ALI in children causes (Figure 1). The typical pulmonary parenchyma features pertinent to this age, such as less alveoli, less complacent lung and highly complacent chest walls, as well as less developed muscles, are contributing factors to more frequent respiratory failure determination.(18,19)

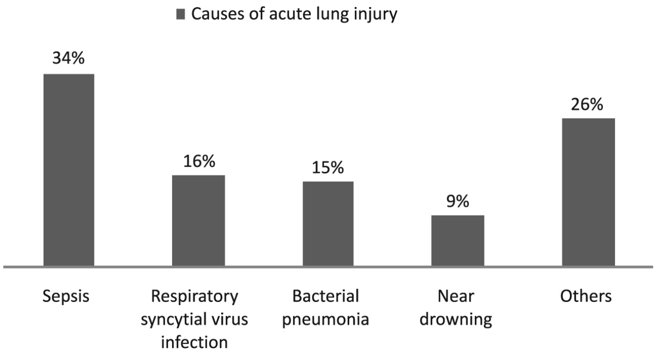


Figure 1 - Clinical disorders associated to acute lung injury in children.(18,19)

Zimmerman et al.(18) had recently presented a study on mortality rate in ALI children. A 12.8 per 100,000 subjects/year rate was identified, being severe sepsis from lung origin the most common risk factor. Hospital mortality was 18%, lower than the previously reported rates for ALI in pediatrics. They concluded that, in this population, the mortality rates are lower than the previous trials findings. Additionally, the incidence was lower than in adults.

ALI is characterized by clinical signs of acute respiratory failure, bilateral pulmonary infiltrate in chest X-rays and PaO_2/FiO_2 rate < 300 mmHg. According to the 1994 American European Consensus Conference (AECC), the most severe ALI picture is the acute respiratory distress syndrome (ARDS), characterized by acute respiratory failure, bilateral pulmonary infiltrate in chest X-rays, and PaO_2/FiO_2 rate < 200 mmHg.(6,14) From a pathophysiologic point of view, ALI/ARDS consists in inflammatory infiltrate filling of alveoli, alveolar collapse, and reduced and heterogeneously distributed aired pulmonary volume. It is considered an inflammatory lung response, with epithelium-endothelium barrier impairment, determining increased alveolar-capillary permeability, reduced complacency, increased pulmonary shunt and worsened artery and tissue oxygenation.(20,21)

Histologically, ALI/ARDS lung injuries are similar to those induced by mechanic ventilation.(22) Several studies compared this lesion to ARDS early phase.(23) The front runner study by Webb & Tierney(24) in 1974 showed that inappropriate MV, with high pressure peaks and low PEEP, may cause biotrauma: inflammatory cytokines release, alveolar edema, epithelial injury and surfactant inactivation. Plötz et al.(25), in 12 anesthetized children who previously were under mechanic ventilation, and no previous lung disease, showed that even ventilated by a short time, they had already signs of biotrauma. This study showed that "non-aggressive" ventilation in normal lungs for a very short time is also able to cause lung insult, triggering the inflammatory response to the blood. These findings suggest that ventilation may be a potent and fast stimulus to several immunological mechanisms interaction, and that the biotrauma word has much a wider meaning.

ALVEOLAR RECRUITMENT MANEUVERS

These are defined as procedures aiming sustained or intermittent trans-pulmonary pressures increase to promote the largest possible alveoli opening, thus improving gas distribution into alveoli. Thus, this approach maximizes the gas exchange and minimizes atelectrauma. ARM is also used for alveolar collapse prevention during low tidal volume mechanic ventilation. Its main objective, however, it to protect lungs from MV-induced injury. PEEP has a fundamental role for maintaining the maneuver efficacy, both preventing derecruitment and atelectrauma.(26,27)

Indications

Alveolar recruitment indication should be preceded by election of the protective ventilatory strategy. In pediatrics, up to 10 ml/kg tidal volumes with plateau pressures below 30 cm H_2O are believed to have a pulmonary parenchyma protective role.(12,28) Its indication is well-established in moderate to severe hypoxemic patients, and also in patients complying with ALI/ARDS diagnosis criteria.(6) Hypoxemic pictures in these patients come from high shunt rates caused by non-aired alveoli.(21,28) Studies recommend ARM to be used in early ALI and ARDS (first 72 hours), as well as in cases of atelectasias due to pulmonary volume loss. It was evidenced that in extra-pulmonary ARDS and sepsis, the lungs are potentially more recruitable.(29,30)

Viral infection ARDS is much more frequent in children than in adults. Histologically, the observed pattern of lung injury is: bronchiolitis, interstitial pneumonitis, and diffused alveolar lesion. With recent advances in knowledge regarding these conditions pathophysiology, ARM may be indicated as complementary therapeutic strategy.(31)

ARM is particularly indicated in situations which can cause alveolar collapse, such as anesthesia, sedation, neuromuscular blockade, as well as removing the patient from ventilator. It can also be used for mobilizing bronchial fluid and reducing lung shunts.(22,28)

In low pulmonary complacency diseases, probably the most important ARM consequence is equalizing lung parenchyma pressure distribution, which is heterogeneous in such conditions. Additionally, these maneuvers prevent normal alveoli hyper-distension situations (volutrauma), partially ventilated alveolar units atelectrauma (collapse), and finally, rescue non-ventilated alveoli. More ventilated alveoli is believed to correspond to better pulmonary compliance, allowing the lung to accommodate larger volumes with lower respiratory system pressures.(30)

In the first Brazilian pediatrics and neonatology MV consensus, ARM had grade C recommendation, as few randomized trials are available in children. The recommendation is that it should be used in acute respiratory failure associated to alveolar collapse children, whenever FiO_2 above 40% is necessary to reach SaO_2 from 90% to 95%. This same consensus considers PaO_2/FiO_2 one of the main ALI/ARDS diagnostic parameters, and a potentially important indication for alveolar recruitment.(32)

Alveolar recruitment techniques

Although MV is routinely used in pediatric intensive care units, alveolar recruitment trials in children are still limited.(28,32) Nevertheless its well proven benefits in adult patients, its use in children is not well established and should be judicious.(4,6,12,32) Lungs and chest wall in childhood are essentially different from adults, as the increased chest complacency, reduced gravity role and lower alveoli numbers. Nevertheless, general recruitment and derecruitment principles are the same.(20)

Prone position has been highly investigated in children as a gravitational strategy to increase oxygenation increase and rescue the lungs. Additionally, it can be associated with ARM, contributing for its effectiveness. Simplicity and lower cost of the prone position, along with its benefits in severe lung injury patients, has popularized this therapy. During the I Brazilian Pediatrics MV Congress, the prone position received grade A recommendation, and is indicated for patients needing $FiO_2 \geq 60\%$, PEEP ≥ 10 for keeping $SaO_2 \geq 90\%$. The prone position "dose" remains to be established. It is indicated to keep the position for up to 7 days from the indication, for at least 6 hours up to 20 hours daily.(32,33)

Different methods are proposed as possible approaches for lung recruitment as high continuous positive airways pressure (CPAP) and gradual PEEP increase maintaining controlled pressure.(4,27,32)

So far the most frequently used recruitment maneuver in MV children is sustained inflation. The technique consists in 30 to 40 cm H_2O CPAP for 30-40 seconds (Figure 2).(34,35)

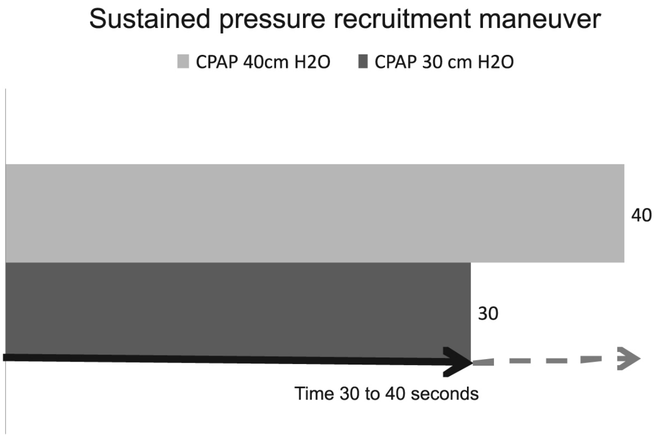
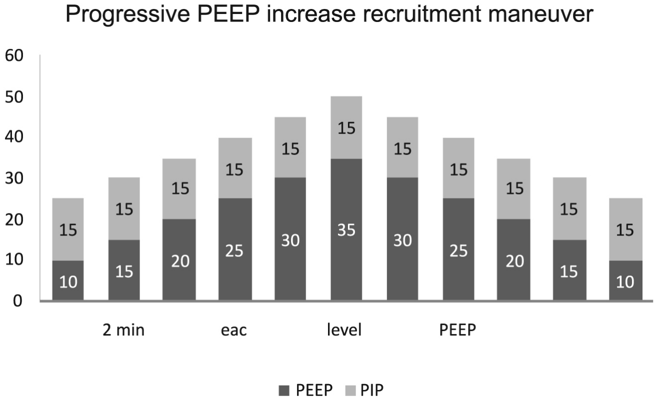


Figure 2 – Sustained insufflation maneuver shows continued 30 or 40 cm H_2O for 30 to 40 seconds.

The second technique uses controlled pressure, where the inspiratory pressure is kept at 15 or 20 cm H_2O, the respiratory rate fixed at 10 mpm and the inspiratory time fixed at 3 seconds. The procedure consists in PEEP increase, starting from at least 10 cm H_2O, gradually increasing by 5 cm H_2O steps for up to 2 minutes, and allowing to reach an up to 35 cm H_2O final PEEP, with a consequent peak pressure increase up to 50 cm H_2O (Figure 3).(32,36,37)



PEEP – positive end-expiratory pressure; PIP - positive inspiratory pressure

Figure 3 - Progressive 5 cm de H_2O PEEP increase every 2 minutes.

For the patient's comfort, sedation and analgesia is recommended. Midazolam and fentalyl infusion, with the dose adjusted as clinically needed is indicated. Patients with severely impaired lung mechanics, and during the acute phase, may need neuromuscular blockade, such as vecuronium, due to agitation, coughing, asynchronia to the ventilator and barotraumas risks.(20,38,39)

The maneuver may be performed several times daily, or as needed. ARM is recommended in the early lung injury, from 24 hours after mechanic ventilation start, up to 72 hours. It can be repeated when oxygenation deteriorates, ventilator is discontinued and/or after tracheal tube aspiration. Tracheal aspiration should be performed before the recruitment procedure. ARM should be repeated whenever tracheal aspiration is needed, for the "open lung" effect assurance.(20,25,32,34,36,38-41)

PEEP allows increased alveolar stability after recruitment.(4,7,9) Pre-established values for children are not available, however adult literature data suggest a safe PEEP values window between 8-15 cm H_2O, resulting in peak pressures below 35 cm H_2O, plateau pressure below 30 cm H_2O and tidal volumes by 5-8 ml/kg. Optimal PEEP would be determined by the optimal gas exchange point, i.e., 2 cm H_2O above the respiratory system pressure-volume curve, watching the hemodynamic stability.(12,32,41,42)

Benefits, adverse effects and complications

For a better results evaluation, should be determined lung injury severity markers, such as PaO_2/FiO_2 rate, OI, pulmonary complacency and lung injury score modified for children by the procedure start and the patient's follow-up.(12) Additionally, it would be important that at each intervention the effectiveness is also checked by imagery techniques (such as chest computed axial tomography and electric impedance tomography), both static and dynamic respiratory mechanics studies, as well as pulmonary volumes measurements.(15,16,25,43)

Experimental ARM trials have shown beneficial oxygenation effects.(7,23,24,26) In a study in healthy children with healthy lungs under anesthesia, the authors showed reduced atelectasia and improved pulmonary complacency.(44,45)

Duff et al.(34) developed a prospective trial involving 32 children with sustained 30 to 40 cm H_2O for 15 to 20 seconds inflations whenever the ventilator was disconnected, trachea was aspired, there was hypoxia or in an every 12 hours routine. During the maneuvers there was no blood pressure, heart rate or oxygen saturation changes, and a significant FIO_2 reduction was seen in the 6 hours following the procedure. They concluded that the maneuvers are safe for pediatric patients, and are associated to a significant oxygen need reduction in the 6 hours following ARM.

In the Rimensberger et al.(46) trial in ARDS low weight newborns with MV associated to high rate oscillatory ventilation, it was found that the treated group stayed shorter under MV, had lower bronchopulmonary dysplasia rate, and less oxygen dependency. Scohy et al.(47) used the recruitment maneuver followed by 8 cm H_2O PEEP in 20 children. A significant improvement was seen in the dynamic complacency, oxygenation, end-respiratory pulmonary volume in post-heart surgery children. In ARDS children, Gaudencio et al.(42) using progressive PEEP levels and 15 cm H_2O controlled pressure until obtaining less than 5% collapse in the tomography, found improved PaO_2/FiO_2 ratio.

However, clinical trials in children have still shown controversial findings.(22,48) In addition to the observed beneficial effects, ARM may also have untoward effects such as inflammatory cytokines release. Halbertsma et al.(48) showed in severely ill MV children, that one single ARM procedure may translocate proinflammatory cytokines from the alveolar space into the systemic circulation. Grasso(43) has recently observed that recruitment may not prevent normal alveolar units hyper-distension. Other observed adverse effects were reduced venous return and cardiac output, and hypotension. The most appropriate way to prevent these effects would be maintaining the intravascular space expansion.(9)

The main complications during the maneuver are barotraumas and hemodynamic impairment. Two mechanisms account for the hemodynamic instability: the first, increased airways pressure leading to reduced venous return and right ventricle preload. The second, increased alveolar pressure, by turn increasing pulmonary vascular resistance and right ventricle afterload.(41) Reduced brain perfusion and bacterial translocation were also reported. A recent systematic review has shown the most frequent complications as hypotension (12%) and dessaturation (9%). Barotrauma, although an important complication, had a low frequency (1%).(49) These effects look to be infrequent and to have low impact compared to the oxygenation improvement needs in severe hypoxemia patients.(28,34,48) Another important issue is the relatively short maneuver effect duration, which may be repeated several times daily to keep the lungs expanded.(41) The Brower et al.(40) study found that the maximal maneuver effect on oxygenation was seen 10 minutes after the maneuver, decreasing by the next 2 to 3 hours.

Among its main contraindications are hemodynamic instability as hypotension, agitation, chronic obstructive pulmonary disease, unilateral lung disease, previous pneumectomy, bronchopleural fistulae, hemoptisis, not-drained pneumothorax, intracranial hypertension, and prolonged mechanic ventilation.(36,39,42)

FINAL COMMENTS

Although protective strategy and ARM use is becoming increasingly accepted and used in children, well defined guidelines for better efficacy are not available. These procedures are not widely accepted in children due to typical pulmonary parenchyma features in younger patients and the need of additional investigations in this population. Thus, its use should be judicious, as the child's lung tissue may directly go from alveolar collapse to even more harmful hyperdistension and rupture.

ARM appears beneficial as adjuvant for oxygen refractory hypoxemia and early pulmonary complacency diseases treatment. In addition to the observed benefits, ARM may also have undesirable effects, such as inflammatory cytokines release. It should be considered that its effects may be transitory. ARM use in acutely ill children should be done under rigorous monitoring, sedation and hemodynamic control, and by an experienced team.

When is the optimal implementation time, and how should its efficacy be evaluated are still challenges for pediatric ICUs. For this, additional studies using these procedures are necessary for better evaluation of its impact on morbidity and mortality in pediatric patients.

RESUMO

Recentes mudanças foram introduzidas na forma de ventilar crianças com doenças que determinam o quadro de insuficiência respiratória aguda hipoxêmica. Há evidências que estratégias ventilatórias menos agressivas, melhoram a sobrevida com grave lesão pulmonar. Estudos experimentais evidenciaram relação entre modalidades ventilatórias inapropriadas e retardo na melhora e até mesmo piora da lesão pulmonar aguda. A partir desta concepção, surge uma estratégia ventilatória protetora, combinada à manobra de recrutamento alveolar. Acredita-se, que esta associação na prática clínica, determina importante redução da morbidade e mortalidade, bem como, prevenção das lesões induzidas pela ventilação mecânica. Sua indicação relaciona-se com quadros de lesão pulmonar aguda, geralmente decorrente de pneumonia ou sepse, que cursam com grave hipoxemia. Suas principais contra-indicações são instabilidade hemodinâmica, presença pneumotórax e hipertensão intracraniana. Estudos experimentais demonstraram efeitos benéficos da manobra sobre a oxigenação e colapso alveolar. Estudos em adultos demonstraram melhora da função pulmonar e reversão da hipoxemia. Em crianças, a manobra demonstrou significativa redução da fração inspirada de oxigênio e do colapso alveolar, menor dependência ao oxigênio, melhora da complacência pulmonar e menor índice de displasia broncopulmonar. Porém, os estudos em pediatria são limitados. Faz-se necessária maior investigação sobre o tema e evidências de sua aplicação clínica. Foi realizada revisão da literatura, com pesquisa de livros-texto e nas bases de dados da MEDLINE, Pubmed, *Cochrane library,* SciELO e Ovid, no período de 1998 até 2009, em português e inglês. Foram incluídas publicações acerca da manobra de recrutamento alveolar em adultos e crianças, artigos de revisão, estudos experimentais e ensaios clínicos utilizando as palavras-chave: estratégia ventilatória protetora, manobra de recrutamento de alveolar, pediatria e ventilação mecânica.

Descritores: Unidades de terapia intensiva; Respiração artificial/efeitos adversos; Mecânica respiratória; Criança

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