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REVIEW

Lung volume recruitment in acute respiratory failure in patients admitted to intensive care facilities

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Abstract. *Objective*: **To investigate from literature how recruitment manoeuvres are being performed and from this information to deduce directions on how to recruit in order to find a standardized and optimal method of lung volume recruitment as a starting point for future clinical trials.** *Search strategy:* **We identified the most relevant English language publications on lung recruitment by searching the Medline database. We limited our search to human adult studies. Thirty-four studies were selected.** *Summary of findings:* **Only a limited number of studies on the use of lung recruitment manoeuvres were available, and only a few patients with diverse follow-up periods were included, the most common category being ALI/ARDS patients. There was some small indication for the superiority of recruitment manoeuvres in patients with extra-pulmonary and early ARDS. CPAP followed by pressure-controlled ventilation was most commonly used during lung recruitment. Maximum airway recruitment pressures are on average 45-50 cmH_2O but may be as high as 80 cmH_2O. Recruitment duration varied between 3.3 seconds and one hour; muscle paralysis was often used. Adjustment of PEEP was not standard practice after recruitment. Improvements in blood oxygenation and respiratory mechanics most commonly defined successful recruitment and their deterioration was cited as a reason to repeat recruitment. Recruitment was found to be most commonly terminated due to haemodynamic instability or barotraumas. The majority of trials studying recruitment manoeuvres favour these procedures.** *Conclusions:* **The categories of patient who profited most from recruitment were those with ALI/ARDS, post-cardiac surgery patients and patients with lung collapse after endotracheal suctioning. We believe the use of the P_aO_2/F_iO_2-ratio (P/F-ratio) is at present the method that best combines practicality with sensitivity in defining the state of openness of a lung. Limiting peak inspiratory recruitment pressures may prevent recruitment of the most severely affected alveoli. Opening pressures should be applied for about 10-15 seconds. Use of pressure-controlled time-cycled modes of mechanical ventilation is preferable to volume-cycled modes of mechanical ventilation and CPAP when performing recruitment. PEEP can prevent collapse of open and perfused alveoli but PEEP itself does not recruit collapsed alveoli because recruitment is an inspiratory phenomenon. Defining the right PEEP level by finding the closing pressure of the alveolar system should always be part of a recruitment protocol. If during ventilation renewed alveolar collapse of alveoli occurs, a fall in P/F-ratio indicates that a re-opening manoeuvre has to be performed.**

Introduction:

Lung volume recruitment can be used as a tool to maintain oxygenation and improve carbon dioxide removal and lung compliance [1]. A trend towards ventilating ARDS patients with smaller tidal volumes would suggest a more important role for lung volume recruitment in the future, as low tidal volume ventilation might lead to derecruitment [2]. Although low tidal volume ventilation has been shown to reduce mortality from ARDS, the impact of recruitment manoeuvres on ICU outcome is still a matter of debate [3]. The use of these procedures originates to some extent from the "open up the lung and keep the lung open" concept introduced by Lachmann [1]. Although this concept is clear in itself, the method of achieving lung recruitment is still a matter of dispute. In order to conduct studies on outcome, however, some attempt should be made to reach agreement on how lung recruitment is best performed.

We will review methods of recruitment, patient categories, the design of the studies and the variability with which lung recruitment manoeuvres are being performed. Several aspects of lung recruitment such as e.g. maximum airway pressure applied, duration of a manoeuvre and the mode of ventilation are reviewed. Whether lung recruitment manoeuvres lead to a reduced mortality in ICU patients is not further discussed here. From our literature findings, we will try to deduce directions towards an "ideal" method of lung recruitment which could be the starting point of more standardized future studies. These could lead to more standardized investigations on the true influence of lung recruitment on ICU outcome.

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Search strategy

We identified the most relevant English language publications on lung recruitment by searching the Medline database. The following search terms were used: (alveolar OR lung OR pulmonary) AND (recruitment OR recruiting) AND (manoeuvre OR manoeuvres OR manoeuvres). We limited our search to human studies and adults (19 years and older).
The search resulted in 56 hits. Six studies which were not published in English, two case reports and one letter concerning lung recruitment were not included in our analysis. The remaining 47 studies were reviewed. Twenty-nine studies which took place either completely or partially in an ICU setting were selected for further analysis. By searching the references of these studies we were able to identify another 22 studies. This resulted in a total of 51 studies. Of these 51 studies, 14 were used as a source of background information [1;3;4-15]. The other 37 were used to evaluate the variability with which recruitment manoeuvres are being applied. Two of these studies reported the same study results so only one of them was used for further analysis [16].

Table 1: Design of the included studies.

Study Design	Reference Number	Number of Studies
Randomized Controlled Trial	16;20;21;22;23	5
Prospective study with randomized cross-over	19;24;25;26;27	5
Prospective trial; randomization failed or a true control group was absent	17;30;42	3
Prospective study with non-randomized cross-over	2;34;36;39	4
Prospective interventional and/or observational and/or comparative	28;29;31-33;37;38; 40;43;44;46-50	15
Retrospective	35;41	2
		34

Another study [17] reproduced data from 19 of 20 patients from a previous preliminary study [18] so only the results of the preliminary study were used. The recruitment manoeuvres of the ARDS network trial on higher versus lower PEEP in ARDS were evaluated in another study [19]. Only the second study was used. A total of 34 studies [2;16;17;19-44;46-50] remained to study the use of recruitment manoeuvres.

Summary of findings

Study designs

Of the 34 selected studies, only five [16;20-23] were truly randomized-controlled trials (RCT). Two of these RCTs [16;21] compared protective ventilation, including recruitment manoeuvres, with conventional ventilation with respect to its effect on functional residual capacity and right ventricular afterload. A study conducted by Amato [23] compared lung protective ventilation (including recruitment manoeuvres) with conventional ventilation, evaluating the effect on 28 day ICU mortality. Two RCT [20;22] investigated the effect of lung recruitment on its own and not as part of a ventilation strategy. Three of five reviewed prospective randomized crossover studies, evaluated recruitment manoeuvres in relation to endotracheal suctioning procedures [24-26]. One [19] concerned lung recruitment in a high PEEP strategy; another [27] in a low PEEP strategy. The other evaluated studies were prospective in design without proper randomization, control group or crossover, or were observational or retrospective (Table 1).

Patient numbers enrolled in the studies

The number of patients investigated in the 34 studies varied between five and a maximum of 96 patients per study (mean 23.1 standard deviation 18.7). Altogether 785 patients were included.

Twenty-eight of 34 (82%) studies were conducted in populations consisting of ALI/ARDS patients only. In 2 two studies (6%) more than half the patients had ALI/ARDS [28;29]. The remaining four (12%) studies investigated patients with no established ALI/ARDS, during and after cardiac surgery [16;21;22;30].

The total number of ALI/ARDS patients was 622 (79%). In 21 (62%) studies [17;19;20;24-26;28;31-44] comprising 448 (57%) patients, the American-European Consensus Conference on ARDS (AECC) criteria for ALI/ARDS [45] were fully applicable. The group of post- and peroperative cardiac surgery patients consisted of 139 (18%) patients [16;21;22;30]. The Lung Injury Score was calculated in 18 studies and varied widely (Table 2).

Duration of study follow-up

Patients were followed for a period shorter then 24 hours in 26/34 (76%) of the studies. Only one study had 28 day survival as an end point [23]. In four studies the duration of follow up was not clear [41;46-48] and in the remaining three [16;35;49], patients were monitored for 48-96 hours.

Table 2: Lung Injury Scores are presented as mean (standard deviation) unless otherwise specified. The study number is the reference number. AECC = American-European Consensus Conference on ARDS definitions. RM = Recruitment Manoeuvre.

Study	Lung Injury Score	ALI/ARDS	AECC
2	2.8 (0.4)	yes	no
17	3.1 (0.4) RM + PEEP group	yes	yes
	3.1 (0.3) RM group		
	3.2 (0.5) PEEP group		
22	1 (median) 0.5-2.0 (range) PEEP group	no	no
	1 (median) 0.75-1.75 (range) ZEEP group		
23	3.4 (0.4) protective ventilation group	yes	no
	3.2 (0.4) conventional ventilation group		
24	2.2 (0.4)	yes	yes
25	2.8 (0.4)	yes	yes
26	3.0 (0.4)	yes	yes
27	3.1 (0.4)	yes	no
28	LIS >2,5 in ARDS group (20 out of 39 patients)	yes, partial	yes
30	1.7 (median) 1.0-2.7 (range) RM group	no	no
	1.6 (median) 0.7-2.3 (range) PEEP group		
	2.0 (median) 1.0-2.3 (range) RM + PEEP group		
33	3.4 (0.3)	yes	yes
37	2.5 (0.4) pulmonary ARDS group	yes	yes
	2.8 (0.4) extrapulmonary ARDS group		
38	2.9 (0.3) responders prone positioning	yes	yes
	3.0 (0.3) non responders prone positioning		
40	3.3 (0.4)	yes	yes
42	3.0 (0.5) Nitric Oxide + RM group	yes	yes
	2.3 (0.7) RM group		
	2.7 (0.5) Nitric Oxide group		
43	3.4 (0.3)	yes	yes
46	2.3 (0.6)	yes	no
48	3.7 (0.7)	yes	no

Studied patient categories

The majority of the patients investigated had ALI/ARDS. Eleven studies reportedly studied early ARDS, although the defined time window for early ARDS ranged from one to seven days [17;19;20;36-39;41-43;49]. One study [31] demonstrated that patients with early ARDS benefited more from lung recruitment manoeuvres than patients with late ARDS. In three other studies [33;35;46] no differentiation was made between early and late ARDS.

Three authors demonstrated that extra-pulmonary ARDS responds better [17;36;37] to recruitment manoeuvres than pulmonary ARDS. No difference in response could be demonstrated between pulmonary and extra-pulmonary ARDS in three other studies [19;31;46].

In two studies, patients on a high PEEP level showed no obvious increase in oxygenation after recruitment [19;20] whereas one study observed recruitment manoeuvres improved oxygenation at a low PEEP setting [27].

Three randomized crossover studies (two in ARDS patients, one in cardiac surgery patients) concerned endotracheal suctioning [24-26]. All showed the value of recruitment manoeuvres in regaining oxygenation or preventing loss of lung volume after suctioning.

Two studies on ARDS patients showed a complementary effect in patients in the prone position when recruitment manoeuvres were

Table 3: Stopping criteria for recruitment manoeuvres or criteria for not starting recruitment manoeuvres. Decreases and increases with regard to baseline values at the start of the recruitment manoeuvre.

Criteria for premature termination of recruitment manoeuvre:
• MAP decreasing more than 20-30%
• Systolic blood pressure decrease to ffi90 mmHg or by more than 30 mmHg or 20 %
• Heart rate change to > 140/min or by more than 20/min or 20 %
• Decrease in SpO2 to < 80-90% or a decrease by ffl 5%
• (New) cardiac dysrhythmia
• Peak airway pressure > 45 cm H2O on more than 3 consecutive breaths
• ICP > 25 mmHg
• CPP < 50 mmHg
• P/F ratio > 250 mmHg
Recruitment manoeuvres not conducted if:
• Systolic blood pressure <100 or >200 mmHg
• Heart rate <70/min or >120-140/min
• Patient was being weaned
• Persistent air leak

Table 4: Parameters used to evaluate the effect of recruitment maneuvers. n = number of studies; maximum is 34.

Study Parameters	Used in n studies
• PaO2, P/F-ratio, peripheral saturation or FiO2	33
• Compliance/elastance	23
• P-V-Curves/Lower Inflection Point (IP)-Upper IP-Expiratory IP	11
• Venous admixture	9
• End Expiratory Lung Volume	8
• Tidal volume	7
• CT-scan lung volume/X-thorax/radiology score	7
• (De-)recruited lung volume (abs/%)	6
• Vd/Vt	5
• Time on ventilator/weaning time	4
• Oxygenation index	2
• Functional Residual Capacity	2
• Resistance of the Respiratory system / Lung / Chest wall	2
• 28 days survival	1
• Survival to hospital discharge	1

used [38;39]. In contrast, Lim et al found that a recruitment manoeuvre was superior in patients in the supine position on comparison with patients in the prone position[17].
Finally normal chest wall mechanics (i.e. no abdominal distention, no pleural effusion) seem to be an important prerequisite for successful recruitment in ARDS [31].

Ventilatory mode used during recruitment

Continuous Positive Airway Pressure (CPAP) was the most commonly used ventilatory mode during recruitment. CPAP was applied in 17 studies (50%) in order to give one or more sustained inflations. A form of Pressure Control Ventilation (PCV), used in nine studies (26%), was the next most commonly applied ventilatory mode [32-35;40;43;47;48;50]. During PCV either the PEEP level, the Peak Inspiratory Pressure (PIP) level or both were increased to achieve recruitment. Another method, used in five studies, was Volume Control Ventilation (VCV) [17;24;27;36;39]. To obtain lung volume recruitment, VCV was combined with an increase of tidal volume (Vt), an increase in PEEP with a reduction of Vt or periodic increases in PEEP. In addition pressure support at a peak pressure of 40 cmH2O was used in one study [26]. In another study both PCV and VCV were used [44] and in one study CPAP was followed by high frequency oscillatory ventilation [49]. None of the studies reported the use of manual recruitment manoeuvres.

Applied maximum airway recruitment pressures

Not all studies clearly specified the maximum allowable peak inspiratory airway pressure for recruitment. In order to establish a commonly used recruitment pressure, we registered the maximum allowed airway pressure if reported in the study. If not reported, we registered the mean or median of the measured maximum airway pressure. We thus found a mean value of 48 ± 8.7 (mean $\pm$ standard deviation (SD)) cmH_2O used in the studies. The highest pressure allowed was 80 cmH_2O [35]; the median pressure was 45 cmH_2O.

Application of Positive End-Expiratory Pressure

Nineteen (56%) studies did not increase PEEP after recruitment. In six of these studies [20;27;36;38;39;42] PEEP was increased before the recruitment manoeuvre. In only six studies was PEEP increased as part of the recruitment manoeuvre [37;40;41;46-48]. In four studies [17;22;29;30] PEEP was increased in only some of the patients or in one study arm. In three of these studies [17;22;30] the authors stated that recruitment was successful only if PEEP was increased. Two studies observed that PEEP was increased if the p_aO_2/F_iO_2-ratio (P/F-ratio) dropped after recruitment [16;21]; in one study PEEP was increased before recruitment and in the event of a drop in P/F-ratio after recruitment [35]. In one case PEEP was shown to decrease if oxygen saturation increased [19]. This study showed no beneficial effects. All in all, PEEP was increased before or after recruitment in at least a some of the patients in 19 of 34 (56%) studies.

Cutting of recruitment manoeuvres and adverse effects

Twelve publications gave criteria on when to stop a recruitment manoeuvre and when not to start it at all [17;19;20;22;25;32;33;38;40;42;43;49] (Table 3). Eight studies did not specify adverse effects in part of their study population [2;17;24;26;28;36;44;48]. Eleven studies observed no adverse effects of recruitment manoeuvre [20;21;27;33;34;38-40;43;46;47]. The most frequently observed adverse effect in the other studies was haemodynamic instability (hypotension, decreased cardiac output, arrhythmia) followed by barotraumas. Desaturation, coughing, decreased perfusion of gastric mucosa and deleterious effects on cerebral perfusion and intracranial pressure were also seen.

Duration of the recruitment procedure

Most recruitment manoeuvres were of short duration. In eight studies recruitment lasted 2-60 minutes [27;34;36;39;40;44;48;50]. In the remaining 26 studies, recruitment lasted less than 2 minutes. Duration varied between 3.3 sec and 1 hour. In the group of recruitment manoeuvres of less than 2 minutes, the mean duration was 49 seconds (SD 31.6; Median 40 seconds).

Repeating recruitment manoeuvres

Most studies did not investigate the frequency with which recruitment manoeuvres had to be repeated. Reasons for repeating a recruitment manoeuvre were a drop in P/F-ratio [16;21;35], desaturations [29] or patient disconnections from the ventilator [16;23;35;37;49]. In four studies, the recruitment manoeuvres were applied once to three times daily [19;41;42;49]. Three others used sighs or intermittent increase in PEEP two to three times per minute for a period of 30 to 60 minutes [27;36;39].

The use of muscle paralysis

In four of 34 studies [19;25;30;32] muscle paralysis was probably not used. In 20 studies muscle paralysis was used in at least some of the patients. The remaining 10 studies [21-24;33;35;43;44;48;49] were unclear about the use of paralysis but in some cases neuromuscular blocking agents may have been used.

Monitoring recruitment

Monitoring the effects of recruitment manoeuvres was done in several different ways in thestudies we reviewed (Table 4). Most studies did not define what a successful recruitment manoeuvre was considered to be. In only 11 studies was a definition of a successful manoeuvre given. A P/F-ratio greater than 250-400 [16;21;35;40], an increase in P/F-ratio [31;33] or the absolute level of oxygenation [43] of 20-50%, a decrease in the inspired oxygen concentration to less than 60% with a peripheral oxygen saturation above 88-93% [28;49], a decrease in the F_iO_2 and PEEP level [19] and achieving 'a maximal elevation' (not further specified) of p_aO_2 [48] were used as markers for success of recruitment.

Functional outcome

Twenty-three studies (68%) favoured lung recruitment manoeuvres either on its own or as part of a protective lung ventilation strategy. In four studies [19;30;31;46] either a subgroup or part of the study population demonstrated the positive effects of recruitment manoeuvres. Four studies [20;32;33;50] could not demonstrate any positive effect of lung recruitment. In three studies [21;28;34] no clear judgment could be made on the effect of recruitment manoeuvres. In two of these studies, the effects on oxygenation and respiratory mechanics of the recruitment manoeuvre were not investigated [21;34]. In one study the recruitment manoeuvre was part of a ventilation strategy but the effects of prone positioning were studied [28].

Discussion

This review shows us that as far as lung recruitment manoeuvres are concerned, little solid evidence is available on how, when and in what patient category to perform lung recruitment. Most clinical studies on recruitment manoeuvres lacked good randomization, used small patient numbers or had a short follow-up period. Only one study considered long term survival [23]. Moreover, the way recruitment was performed differed in almost all studies which make them hard to compare. We will now, however, try to deduce directions on how to best perform a recruitment manoeuvre. In order to do so we will combine the results of the reviewed studies with data out of experiments, theories and theoretical background because the reviewed studies lack a high level of evidence.

Patient categories

Depending on the criteria used, in 57-79 % of the studies ALI/ARDS patients were investigated although they had a wide range of Lung Injury Scores. Small indications exist for superiority of recruitment manoeuvres in patients with extra-pulmonary and early ARDS. Up to now, this could only be substantiated for early ARDS in one study and for extra-pulmonary ARDS in three studies. Further research is warranted. The choice of these patient categories seems logical considering the pathophysiology of ARDS/ALI [51;52]. Alveolar flooding in ARDS will not occur as long as the suction force in the pulmonary interstitium exceeds the pressure gradient generated by the surface tension in the alveolar air-liquid interface. An increased surface tension can be counteracted by the application of airway pressures and this prevents and reduces alveolar flooding [53]. Recruitment seems therefore to be useful only in early ARDS when the lung is flooded with proteinacious oedema and not in the later phase involving fibrotic organization of the lung [54]. This furthermore explains why recruitment manoeuvres may be more effective in extra-pulmonary ARDS where the mechanism of injury involves alveolar flooding via the bloodstream. In contrast, pulmonary ARDS involves a direct injury to the lung cells [55].

Most of the other patients studied had undergone cardiac surgery. In this patient category there may be an extra-pulmonary cause of ARDS due to a systemic inflammatory response syndrome after cardiopulmonary bypass [56]. Moreover, opening of the thoracic cage may lead to alveolar collapse.

In relation to endotracheal suctioning in both patient categories (ALI/ARDS and cardiac surgery) recruitment manoeuvres appear to be a useful tool [24-26].

When considering prone positioning in ARDS, it is important to bear in mind that its effect on oxygenation is variable and wears off after one week of mechanical ventilation [57]; the aetiology of ARDS may markedly affect the response to prone positioning and criteria to apply it are non-standardized and vary between centres. Considering these facts, it is not surprising that recruitment manoeuvres using different protocols during prone positioning gave variable results [17;38;39].

The most common cause of decreased compliance of the lung/chest wall system in ALI/ARDS patients, is intra-abdominal hypertension [58]. Logically, pleural effusion will also decrease compliance. Therefore both intra-abdominal hypertension and pleural effusion will oppose pressure applied externally by mechanical ventilation and may hamper the positive effect of recruitment manoeuvres [31].

How do you open up a lung?

The careful reader may be confused when looking at the presented lack of evidence and will ask himself: "Which mode on the ventilator should I use?", "How should I recruit: increasing PEEP levels or increasing PIP levels?", "How high should recruitment pressures be and for how long should they be applied?", and "How to apply PEEP?"

Mode of mechanical ventilation

The reviewed studies provide no clear answers with regard to which mode of mechanical ventilation to use for recruitment. On theoretical grounds, we prefer pressure-controlled modes. The application of volume-controlled mechanical ventilation in the unopened lung will predominantly ventilate the aerated healthy portion of the lung with overdistension in the healthy regions. To reduce dangerous alveolar overdistension, the use of pressure-controlled time-cycled modes of mechanical ventilation in which the alveolar pressure can never exceed the peak inspiratory pressure set on the ventilator seems preferable [59]. Unfortunately, pressure-controlled modes of mechanical ventilation were only used during recruitment in 29 % of the cases studied and volume-controlled ventilation continued to be used in 15 % of cases.

Applied maximum airway pressures

Recruitment pressures in most clinical studies have been limited to a maximum of 50 cmH_2O [18;19;23;33;43]. We found a value of 45-50 cmH_2O used in most studies. Restricting peak pressures is most likely caused by fear of peak inspiratory overstretching with the risk of causing harm to relatively healthy lung units [60;61]. However,

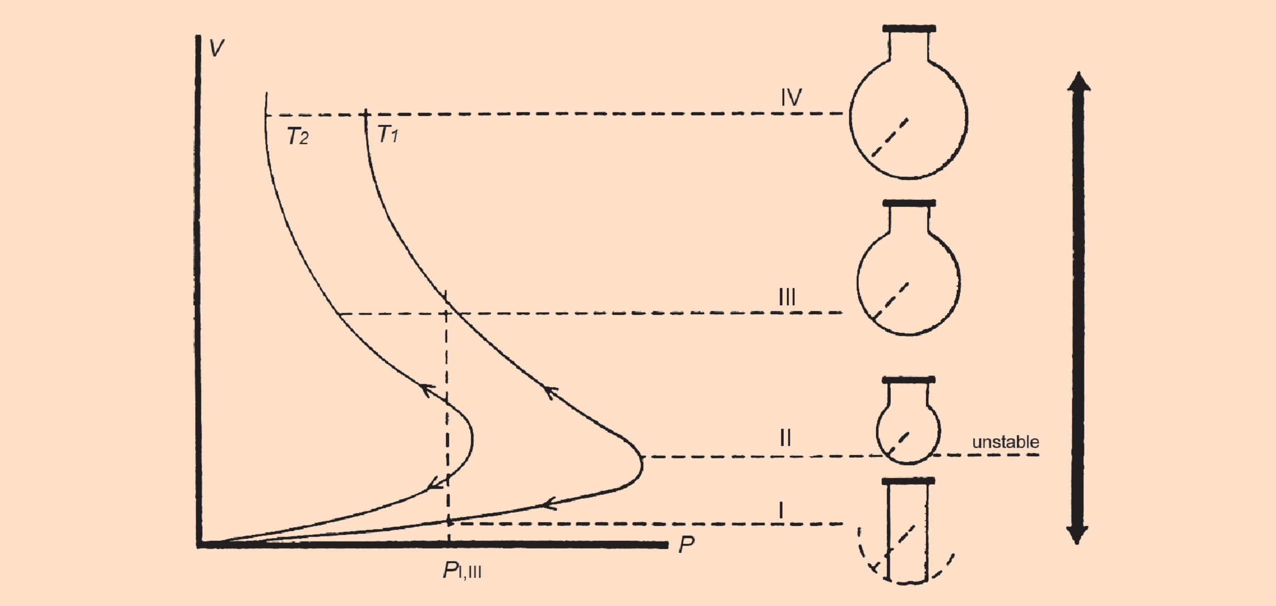

Figure 1. Physiological behavior of the alveolus. The pressure-volume (P-V) relation is shown on the X-Y axes. The right side shows the status of the broncho-alveolar unit: its radius (r) reflects the P-V relation (I-IV). Surface tension in pathological (T1) and normal conditions (T2) is shown. The arrows indicate the direction from closed (bottom) to open (top) states and vice versa [53].

physiologically, a maximum recruitment pressure cannot be defined as it is dependent on the level of surfactant impairment. Limiting peak inspiratory pressures may even prevent recruitment of the most severely affected alveoli.

This review does not deliver clear guidelines on the maximum airway pressures necessary to open collapsed alveoli and so again, we have to look at basic pathophysiology and theory. To recruit collapsed alveoli, a high opening pressure is needed. The rationale behind the high opening pressure to recruit the lung and the need for lower pressures to keep the alveoli open can be deduced from the P-V curve of an individual alveolus (Figure 1). A critical opening pressure has to be reached before collapsed alveoli can be opened. Once open, alveoli remain open until the pressure drops below a critical level and then immediate collapse occurs. Before limiting pressures and/or volumes in a lung protective strategy, the lung should be recruited as low tidal volume ventilation might lead to derecruitment. Opening pressures do not have to be applied for long periods of time as they may also be possibly detrimental. If the pressure is high enough, the alveolus will open up, if not it will remain closed and therefore 2-3 respiratory cycles e.g. 10-15 seconds depending on the time constants, should be enough.

Application of PEEP

PEEP levels were increased in only 56% of the studies, although increasing PEEP as part of a recruitment manoeuvre seems a proper thing to do. The use of PEEP can prevent collapse of open and perfused alveoli but PEEP itself does not recruit collapsed alveoli because recruitment is an inspiratory phenomenon [17].

PEEP can indirectly create a higher end-inspiratory pressure and in that way indirectly re-open collapsed lung areas [62] but it probably should not be primarily used to recruit. Considering these facts, it is not logical to find that 53% of the studies on recruitment were performed by using CPAP. However PEEP has a critical role in recruitment manoeuvres. After recruiting collapsed alveoli, they should be kept open by using a pressure above the critical closing pressure of the alveolus with a sufficiently high PEEP level (Figure 1).

It is known that high PEEP levels of 13-15 cmH_2O and above are necessary to prevent repetitive collapse of alveoli in ARDS patients [63]. Furthermore, only studies on mechanical ventilation using average PEEP levels above 15 cmH_2O in their protective arm, have demonstrated a reduction in mortality in ARDS patients [53]. A recent study by the ARDSnet study concerning higher versus lower PEEP levels during a low tidal ventilation strategy, does not underscore such findings [64]. PEEP levels did not influence outcome in this study. However, arguments against this studyinclude its design, the lack of a proper physiological recruitment background, the difference in baseline characteristics of the two study groups, and the creation of auto-PEEP in the group with low PEEP settings [74].

Thus, PEEP level should be used to prevent recollapse of alveoli. Defining the right PEEP level by finding the closing pressure of the alveolar system (Figure 1) should initially always be part of a recruitment protocol. If set too low, recollapse will occur and the recruitment peak inspiratory pressure will have to be re-applied with a higher level of PEEP set on the ventilator in order to prevent alveolar recollapse.

Cutting of recruitment manoeuvres and adverse effects

The issue of when to break off a recruitment manoeuvre also involves the question when not to start with a recruitment manoeuvre at all. The criteria used to stop or not start a lung recruitment manoeuvre as defined in the studies are listed in Table 3.

As well as these criteria, we believe that the following should be identified as contraindications to starting a recruitment manoeuvre; significant right ventricular failure; patients with a low circulating volume or cardiac compromised patients; severe airway obstruction/ COPD; focal lung problems (e.g. large pulmonary infiltrate/ abscess); lung transplant patients or patients with newly placed bronchial sutures; patients with a pneumothorax and patients with a subarachnoidal bleeding or signs of increased intracranial pressure.

The two main adverse effects of recruitment manoeuvres reported in literature are haemodynamic impairment and barotrauma. Reis Miranda et al. studied right ventricular afterload during recruitment manoeuvres in patients after cardiac surgery with an open pericardium and could find no significant effect on cardiac index, right ventricular preload, contractility and afterload [21]. Findings from other authors confirm that recruitment manoeuvres do not have to result in major

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