

Lung recruitment

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Computed tomography assessment of PEEP-induced alveolar recruitment in patients with severe COVID-19 pneumonia

Ball L, Robba C, Maiello L, Herrmann J, Gerard SE, Xin Y, Battaglini D, Brunetti I, Minetti G, Seitun S, Vena A, Giacobbe DR, Bassetti M, Rocco PRM, Cereda M, Castellan L, Patroniti N, Pelosi P; GECOVID (GEnoa COVID-19) group

Crit Care. 2021 Feb 24;25(1):81

PMID 33627160, <http://www.ncbi.nlm.nih.gov/pubmed/33627160>

Design	Observational study
Patients	42 patients with severe COVID-19 pneumonia
Objectives	Investigate the effects of two levels of PEEP on alveolar recruitment in performing computed tomography to quantify aeration at 8 and 16 cmH ₂ O PEEP
Main Results	Alveolar recruitment was 2.7 [0.7–4.5]% of lung weight and was not associated with excess lung weight, PaO ₂ /FiO ₂ ratio, compliance, inflammatory, and thrombophilia markers. Compared to non-recruiters, patients in the upper quartile of recruitment (recruiters) had similar clinical characteristics, lung weight, and gas volume. Alveolar recruitment was not different in patients with lower versus higher compliance. Increasing PEEP decreased compliance.
Conclusion	In patients with severe COVID-19 pneumonia, higher PEEP resulted in limited alveolar recruitment. These findings suggest limiting PEEP strictly to the values necessary to maintain oxygenation, thus avoiding the use of higher PEEP levels.

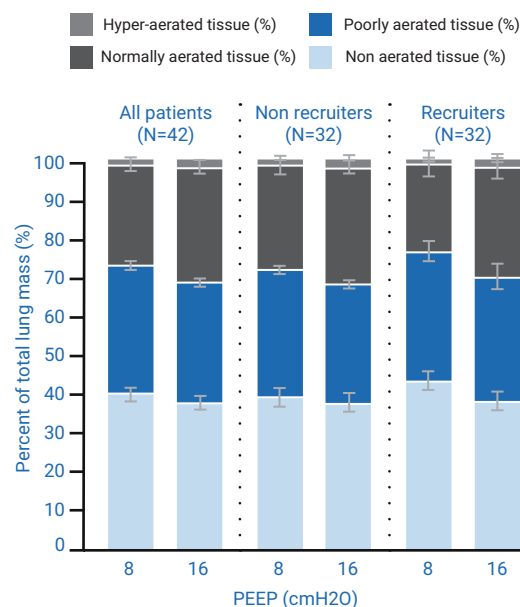


Figure 1: Recruiters and non-recruiters had the same distribution of aeration

Personalised mechanical ventilation tailored to lung morphology versus low positive end-expiratory pressure for patients with acute respiratory distress syndrome in France (the LIVE study): a multicentre, single-blind, randomised controlled trial

Constantin JM, Jabaudon M, Lefrant JY, Jaber S, Quenot JP, Langeron O, Ferrandière M, Grelon F, Seguin P, Ichai C, Veber B, Souweine B, Uberti T, Lasocki S, Legay F, Leone M, Eisenmann N, Dahyot-Fizelier C, Dupont H, Asehnoune K, Sossou A, Chanques G, Muller L, Bazin JE, Monsel A, Borao L, Garcier JM, Rouby JJ, Pereira B, Futier E; AZUREA Network.

Lancet Respir Med. 2019 Oct;7(10):870-880

PMID 31399381, <http://www.ncbi.nlm.nih.gov/pubmed/31399381>

Design	Multicentre (in 20 university or non-university intensive care units in France), single-blind, stratified, parallel-group, randomised controlled trial: In the control group, patients received a tidal volume of 6 ml/kgPBW, PEEP was selected according to a low PEEP/FiO ₂ table, and early prone position was encouraged. In the personalised group, the treatment approach was based on lung morphology; patients with focal ARDS received a tidal volume of 8 ml/kg, low PEEP, and prone position. Patients with non-focal ARDS received a tidal volume of 6 ml/kg, along with recruitment manoeuvres and high PEEP.
Patients	420 patients with moderate-to-severe ARDS for less than 12 h were randomly assigned to either the control group or the personalised group
Objectives	Test whether a mechanical ventilation strategy personalised to individual patients' lung morphology (low PEEP, high tidal volume, and early prone position for focal ARDS and recruitment manoeuvres and high PEEP for non-focal ARDS) would improve the survival of patients with ARDS in comparison to the well established low-PEEP strategy
Main Results	Eleven patients in the personalised group and nine patients in the control group were excluded; 196 patients in the personalised group and 204 in the control group were included in the analysis. In a multivariate analysis, there was no difference in 90-day mortality between the group. However, misclassification of patients as having focal or non-focal ARDS by the investigators was observed in 85 (21%) of 400 patients. There was a significant interaction between misclassification and randomised group allocation with respect to the primary outcome ($p < 0.001$). In the subgroup analysis, the 90-day mortality of the misclassified patients was higher in the personalised group (26 [65%] of 40 patients) than in the control group (18 [32%] of 57 patients).
Conclusion	Personalisation of mechanical ventilation did not decrease mortality in patients with ARDS, possibly because of the misclassification of 21% of patients. A ventilator strategy misaligned with lung morphology substantially increases mortality. Whether improvement in ARDS phenotyping can decrease mortality should be assessed in a future study.

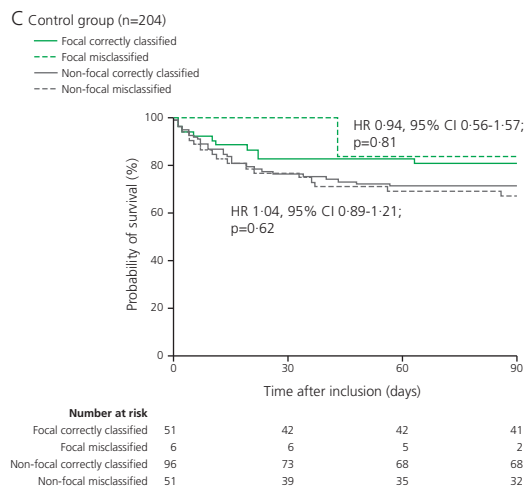
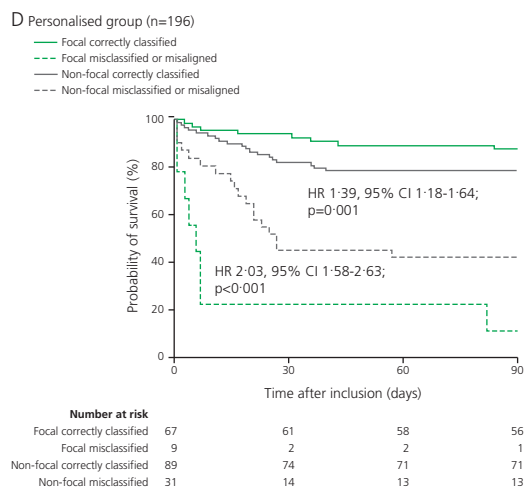


Figure 2: High mortality was observed among the misclassified patients for whom the misaligned ventilator strategy was applied. Analysis of patients whose lung morphology was correctly classified at inclusion revealed a significant increase in survival for those in the personalised group. This finding suggests that misclassification of lung morphology might have concealed a potential beneficial effect of personalised mechanical ventilation on survival



Effect of lung recruitment and titrated positive end-expiratory pressure (PEEP) vs. low PEEP on mortality in patients with acute respiratory distress syndrome: A randomized clinical trial.

Writing group for the alveolar recruitment for acute respiratory distress syndrome trial (ART) Investigators, Cavalcanti AB, Suzumura ÉA, Laranjeira LN, Paisani DM, Damiani LP, Guimarães HP, Romano ER, Regenga MM, Taniguchi LNT, Teixeira C, Pinheiro de Oliveira R, Machado FR, Diaz-Quijano FA, Filho MSA, Maia IS, Caser EB, Filho WO, Borges MC, Martins PA, Matsui M, Ospina-Tascón GA, Giancursi TS, Giraldo-Ramirez ND, Vieira SRR, Assef MDGPL, Hasan MS, Szczeklik W, Rios F, Amato MBP, Berwanger O, Ribeiro de Carvalho CR.

JAMA. 2017 Oct 10;318(14):1335-1345

PMID 28973363, <http://www.ncbi.nlm.nih.gov/pubmed/28973363>

Design	Multicenter, randomized trial conducted at 120 ICU, 9 countries
Patients	1010 moderate to severe ARDS
Objectives	Determine if RM (recruitment maneuver) with PEEP titration according to the best respiratory-system compliance decreases 28-day mortality
Main Results	Experimental group strategy had an increase in 6-month mortality (65.3% vs. 59.9%; $p = 0.04$), a decrease in the number of mean ventilator-free days (5.3 vs. 6.4; $p = 0.03$), and an increase in the risk of barotrauma and in the risk of pneumothorax requiring drainage. There were no significant differences in the length of ICU stay, length of hospital stay, ICU mortality, and in-hospital mortality.
Conclusion	Without a prior recruitability assessment, a strategy of lung recruitment and titrated PEEP increased 28-day all-cause mortality compared with low PEEP.
Comment	A lot of limitations: - COPD and emphysema were not contraindicated and they have an increased risk of pneumothorax - Recruitability was not assessed before the RM and most of the patients (>60%) had a pulmonary ARDS (usually less recruitable), the ART trial did not distinguish between responders and non-responders - The staircase RM is a prolonged increase in pressure with high level of pressure. A mean reduction in driving pressure of only 2 cmH ₂ O was found, indicating that the recruitment maneuver was inadequate to open up the lung and increase functional residual capacity in most patients. - Mortality is 60% vs. supposed 36% - Only 10% of the patients were in prone position - Inclusion from november 2011 to April 2017 = 66 month i.e 3 patients /month with 120 ICU - Double triggering and breath stacking was very likely common due to tidal volumes <6ml/kg - Patients were evaluated under a standardized ventilator setting using PEEP ≥10 and FiO ₂ = 1 for 30 min. Only patients with a persistent PaO ₂ /FiO ₂ ≤200 were eligible for randomization.

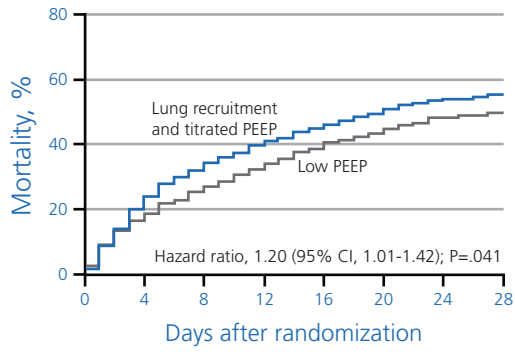


Figure 3: Kaplan Meier curve shows an increase in mortality in RM group

Effect of intensive vs moderate alveolar recruitment strategies added to lung-protective ventilation on postoperative pulmonary complications: a randomized clinical trial

Costa Leme A, Hajjar LA, Volpe MS, Fukushima JT, De Santis Santiago RR, Osawa EA, Pinheiro de Almeida J, Gerent AM, Franco RA, Zanetti Feltrim MI, Nozawa E, de Moraes Coimbra VR, de Moraes Ianotti R, Hashizume CS, Kalil Filho R, Auler JO Jr, Jatene FB, Gomes Galas FR, Amato MB

JAMA. 2017 Apr 11;317(14):1422-1432

PMID 28322416, <http://www.ncbi.nlm.nih.gov/pubmed/28322416>

Design	Prospective randomized trial: intensive (high-pressure recruitment maneuver and PEEP = 13 cmH ₂ O) or moderate (low-pressure recruitment maneuver and PEEP = 8 cmH ₂ O) recruitment strategy
Patients	320 hypoxemic patients after cardiac surgery
Objectives	Assess the effect of an intensive alveolar recruitment strategy on postoperative pulmonary complications in patients receiving lung-protective ventilation with small tidal volumes
Main Results	The intensive recruitment strategy group had a mean 1.8 (1.7-2.0) and a median 1.7 (1.0-2.0) pulmonary complications score versus 2.1 (2.0-2.3) and 2.0 (1.5-3.0) for the moderate strategy group. The mean hospital stay for the intensive group was 10.9 days versus 12.4 days in the moderate group ($p = 0.04$). The mean ICU stay for the intensive group was 3.8 days versus 4.8 days for the moderate group ($p = 0.01$). Hospital mortality was 2.5% in the intensive group versus 4.9% in the moderate group ($p > 0.05$).
Conclusion	Among patients with hypoxemia after cardiac surgery, the use of an intensive alveolar recruitment strategy resulted in fewer severe pulmonary complications than a moderate recruitment strategy.
Comment	This study assesses the effect of an intensive recruitment strategy on complications in post-cardiac surgery patients

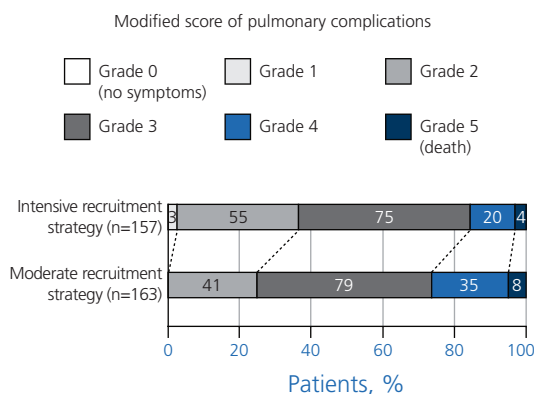


Figure 4: The severity and occurrence of postoperative pulmonary complications were reduced by use of an intensive recruitment strategy

Open lung approach for the acute respiratory distress syndrome: A pilot, randomized controlled trial

Kacmarek RM, Villar J, Sulemanji D, Montiel R, Ferrando C, Blanco J, Koh Y, Soler JA, Martínez D, Hernández M, Tucci M, Borges JB, Lubillo S, Santos A, Araujo JB, Amato MB, Suárez-Sipmann F
Open Lung Approach Network. Crit Care Med. 2016 Jan;44(1):32-42
PMID 26672923, <http://www.ncbi.nlm.nih.gov/pubmed/26672923>

Design	Prospective, multicenter, pilot, randomized controlled trial
Patients	200 moderate to severe early onset ARDS
Objectives	Compared the ARDSnet protocol using low levels of PEEP with open lung approach (OLA = recruitment maneuver and decremental PEEP trial based on the best compliance)
Main Results	Mortality at day 60 (29% OLA vs. 33% ARDSnet protocol, $p=0.18$), ICU mortality (25% OLA vs. 30% ARDSnet protocol, $p = 0.53$), and ventilator-free days (8 [0-20] OLA vs. 7 [0-20] d ARDSnet protocol, $p = 0.53$) were not significantly different. Airway driving pressure and $\text{PaO}_2/\text{FIO}_2$ improved significantly at 24, 48 and 72 hours in patients in OLA compared with patients in ARDSnet protocol
Conclusion	OLA improved oxygenation and driving pressure

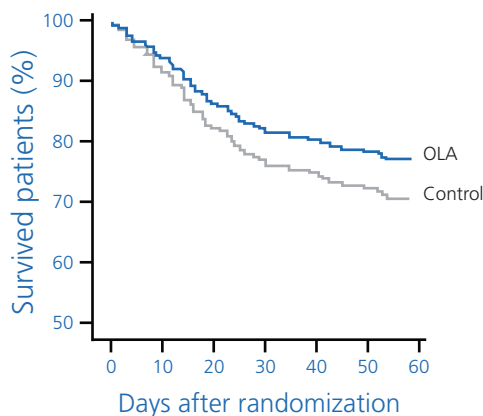


Figure 5: OLA was associated with better survival (with no statistically significant difference) in this pilot study, but a large, randomized controlled trial should be performed to compare outcomes between OLA and the ARDSnet protocol

How large is the lung recruitability in early acute respiratory distress syndrome: a prospective case series of patients monitored by computed tomography

de Matos GF, Stanzani F, Passos RH, Fontana MF, Albaladejo R, Caserta RE, Santos DC, Borges JB, Amato MB, Barbas CS

Crit Care. 2012 Jan 8;16(1):R4

PMID 22226331, <http://www.ncbi.nlm.nih.gov/pubmed/22226331>

Design	Prospective interventional study: Maximal recruitment strategy (MRS) staircase RM (recruitment maneuver) up to 45 cmH ₂ O
Patients	51 early severe ARDS patients
Objectives	Describes the effects of maximal recruitment strategy
Main Results	The opening plateau-pressure was 60 ±6 cmH ₂ O. Mean PaO ₂ /FiO ₂ ratio increased from 125 ±43 to 300 ±103 after RM and was sustained above 300 throughout seven days. Non-aerated parenchyma decreased significantly from 54% [42-62] to 13% [5-24] RM. The potentially recruitable lung was estimated at 45% [25-53]. ICU mortality = 28% and hospital mortality = 33%.
Conclusion	MRS reversed hypoxemia and most of the collapsed lung tissue during the early stages of ARDS.

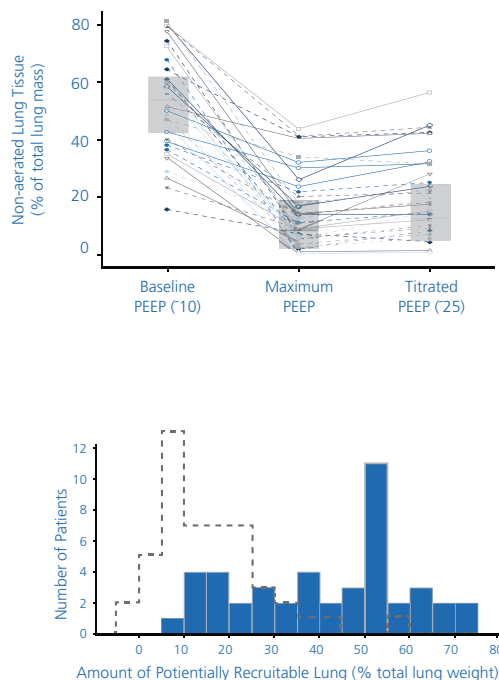


Figure 6: RM followed by PEEP titration allowed a decrease of non-aerated tissue. Potential for recruitment is variable among ARDS patients and seems higher in early onset ARDS patients (grey histogram) than late ARDS patients (dashed lines)

Optimal duration of a sustained inflation recruitment maneuver in ARDS patients

Arnal JM, Paquet J, Wysocki M, Demory D, Donati S, Granier I, Corno G, Durand-Gasselin J

Intensive Care Med. 2011 Oct;37(10):1588-94

PMID 21858522, <http://www.ncbi.nlm.nih.gov/pubmed/21858522>

Design	Prospective interventional study: 30 seconds sustained inflation at 40 cmH2O
Patients	50 early ARDS patients
Objectives	Measure the dynamics of recruitment and the hemodynamic status during RM (recruitment maneuver)
Main Results	The average volume increase was 210 ± 198 ml. Time constant was 2.3 ± 1.3 s. Systolic and mean arterial pressures were maintained at 10 s, decreased significantly at 20 and 30 s during the RM, and recovered to the pre-RM value 30 s after the end of the RM. Heart rate, diastolic arterial pressure, and SpO2 did not change during or after the RM.
Conclusion	Most of the recruitment occurred during the first 10 s and hemodynamic impairment was significant after 10 s = The optimal duration of RM by sustained inflation is around 10 s

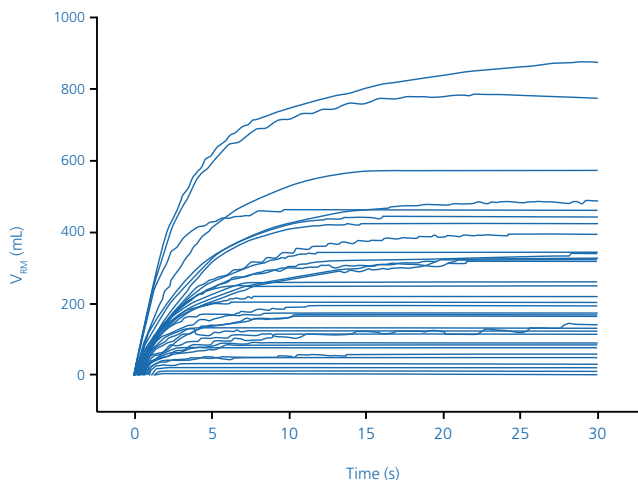


Figure 7: Individual curves of sustained inflation showed that 10 seconds were sufficient to achieve the maximal increase in volume

Prone position and recruitment manoeuvre: the combined effect improves oxygenation

Rival G, Patry C, Floret N, Navellou JC, Belle E, Capellier G

Crit Care. 2011 May;15(3):R125

PMID 21575205, <http://www.ncbi.nlm.nih.gov/pubmed/21575205>

Design	Prospective interventional study: Each patient was ventilated 6h in both the supine position (SP) and the prone position (PP). A 45 cmH ₂ O extended sigh in PC was performed at the beginning of SP RM1 (recruitment maneuver), one hour after turning to the PP (RM2) and at the end of the 6h PP period (RM3).
Patients	16 early ARDS patients
Objectives	Study the effects on oxygenation of both RM and PP
Main Results	Improvements in PaO ₂ level and PaO ₂ /FiO ₂ ratio were transient in SP but durable during PP. PaO ₂ /FiO ₂ changes were significant only after RM3. This global strategy had a benefit with regard to oxygenation: PaO ₂ /FiO ₂ ratio increased from 98 mmHg to 166 mmHg 13 hours later at the end of the study. Pplat (plateau pressure) at decreased after each RM and over the entire PP period.
Conclusion	Combined RM and PP increased oxygenation
Comment	This RM method is associated with high VT with a risk of volutrauma.

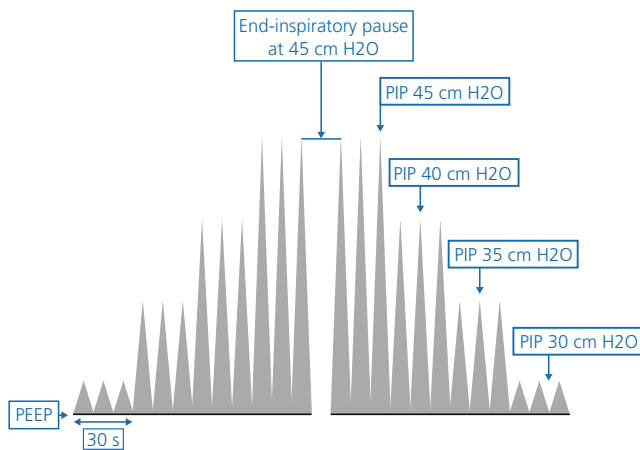


Figure 8: Recruitment protocol in pressure control ventilation: increase of P_{insp} by 5 cmH₂O every 30s, to 45 cmH₂O; then a 30 s pause is performed; then P_{insp} is decrease by 5 cmH₂O every 30 s to baseline.

Clinical efficacy and safety of recruitment maneuver in patients with acute respiratory distress syndrome using low tidal volume ventilation: a multicentre randomized controlled clinical trial

Xi XM, Jiang L, Zhu B; RM group

Chin Med J. 2010 Nov;123(21):3100-5

PMID 21162963, <http://www.ncbi.nlm.nih.gov/pubmed/21162963>

Design	Multicenter RCT: 40 seconds sustained inflation at 40 cmH2O/8 h during 5 days versus no RM (recruitment maneuver)
Patients	110 ARDS patients
Objectives	Evaluate the clinical efficacy and safety of RM
Main Results	In the RM group the PaO ₂ /FiO ₂ was increased compared to baseline on day one and day two (P = 0.007 and P = 0.001). There were no significant differences in hospital mortality, 28-day mortality and ventilator-free days at day 28. ICU mortality (32.7% vs. 52.7%), the rate of survival with unassisted breathing for at least 48 consecutive hours at day 28 (58.2% vs. 36.2%) and nonpulmonary organ failure-free days at day 28 (17 ±11 vs. 13 ±12) favored the RM group.
Conclusion	RM had beneficial impact on clinical outcome

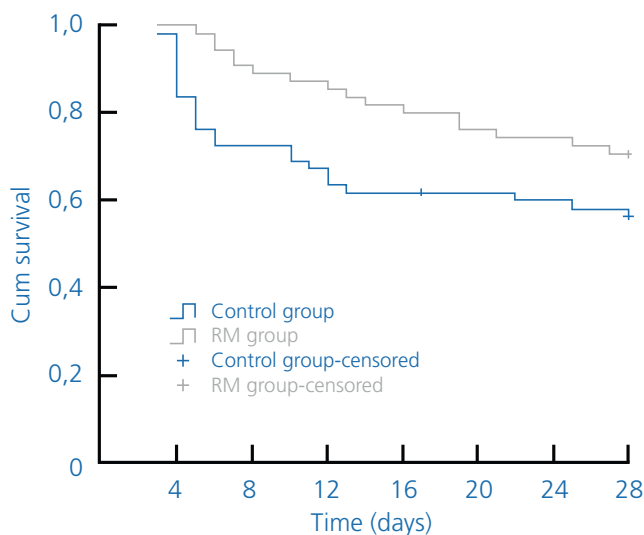


Figure 9: RM increased survival in ARDS patients

A recruitment maneuver increases oxygenation after intubation of hypoxemic intensive care unit patients: a randomized controlled study

Constantin JM, Futier E, Cherprenet AL, Chanques G, Guerin R, Cayot-Constantin S, Jabaudon M, Perbet S, Chartier C, Jung B, Guelon D, Jaber S, Bazin JE

Crit Care. 2010 Apr;14(2):R76

PMID 20426859, <http://www.ncbi.nlm.nih.gov/pubmed/20426859>

Design	RCT: 30 seconds sustained inflation at 40 cmH ₂ O versus no RM (recruitment maneuver)
Patients	40 patients intubated for acute hypoxemic respiratory failure
Objectives	Evaluate the efficacy and safety of RMs performed immediately after intubation
Main Results	5 min after intubation, PaO ₂ obtained under 100% FiO ₂ was significantly higher in the RM group compared with the control group (93 ±36 vs 236 ±117 mmHg). The difference remained significant at 30 minutes with 110 ±39 and 180 ±79 mmHg, respectively, for the control and RM groups. RM was not associated with increased adverse effects.
Conclusion	RM following intubation in hypoxemic patients improved oxygenation

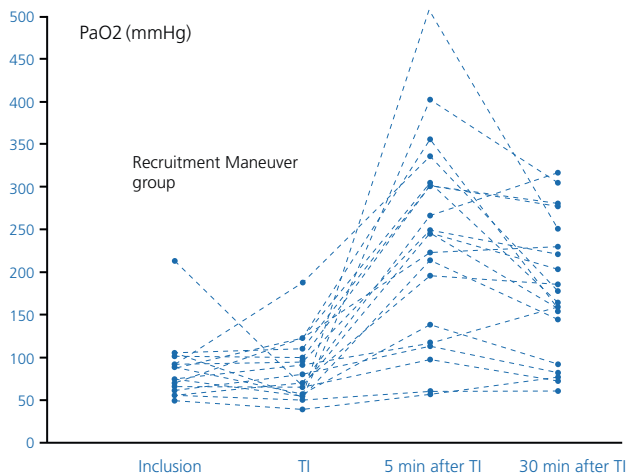


Figure 10: RM after intubation increased oxygenation, and oxygenation remained high after 30 min

Reversibility of lung collapse and hypoxemia in early acute respiratory distress syndrome

Borges JB, Okamoto VN, Matos GF, Caramez MP, Arantes PR, Barros F, Souza CE, Victorino JA, Kacmarek RM, Barbas CS, Carvalho CR, Amato MB

Am J Respir Crit Care Med. 2006 Aug 1;174(3):268-78

PMID 16690982, <http://www.ncbi.nlm.nih.gov/pubmed/16690982>

Design	Prospective interventional study: Maximal recruitment strategy, staircase RM (recruitment maneuver) up to 45 cmH ₂ O
Patients	26 ARDS patients
Objectives	Test if RM is clinically applicable in early ARDS
Main Results	There was an improvement in oxygenation and reduction in the percent mass of collapsed tissue between Paw (airway pressure) = 40 and 60 cmH ₂ O.
Conclusion	In early ARDS it was possible to open the lung in the majority of patients

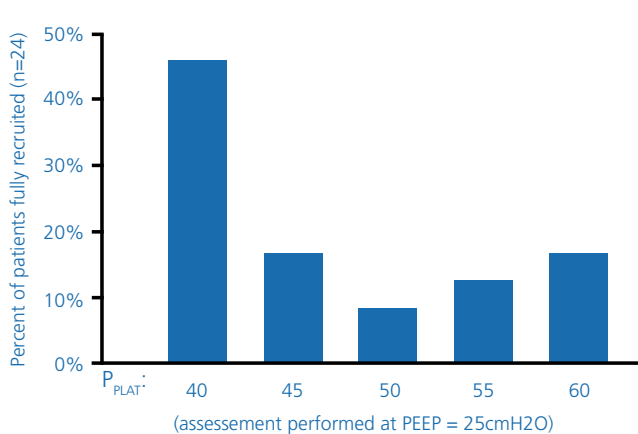


Figure 11: Some patients needed Pplat (plateau pressure) = 60cmH₂O to full recruitment

Lung recruitment in patients with the acute respiratory distress syndrome

Gattinoni L, Caironi P, Cressoni M, Chiumello D, Ranieri VM, Quintel M, Russo S, Patroniti N, Cornejo R, Bugedo G

N Engl J Med. 2006 Apr 27;354(17):1775-86

PMID 16641394, <http://www.ncbi.nlm.nih.gov/pubmed/16641394>

Design	Prospective interventional study: PC with Pplat (plateau pressure) = 45 cmH2O
Patients	68 ARDS patients
Objectives	Examine the relationship between the percentage of potentially recruitable lung and the clinical and physiological effects of RM (recruitment maneuver)
Main Results	Patients with a higher percentage of potentially recruitable lung had greater total lung weights, poorer oxygenation, lower Crs (compliance of respiratory system), higher levels of dead space and higher rates of death than patients with a lower percentage of potentially recruitable lung.
Conclusion	In ARDS, the percentage of potentially recruitable lung is extremely variable and is strongly associated with the response to PEEP
Comment	PEEP was not set according to recruitability. Setting low PEEP in patient with high potential of recruitable lung increases VILI and mortality.

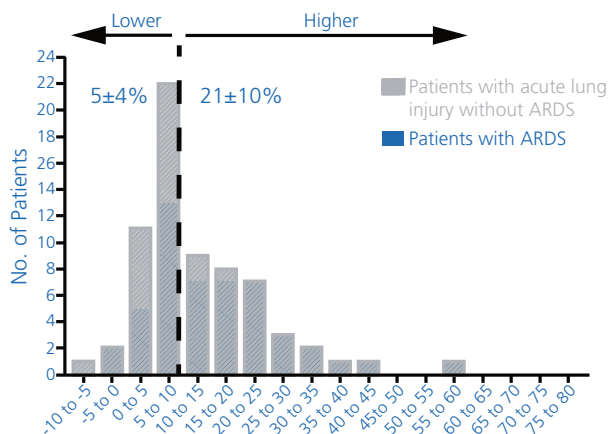
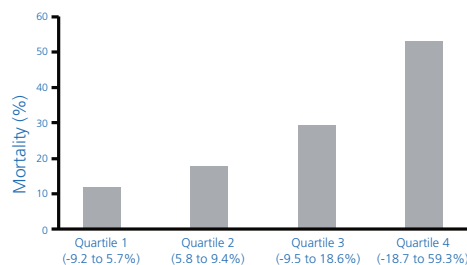


Figure 12: The potential of recruitability is different from patient to patient in ARDS. The patient with the highest potential of recruitability are those with the worst prognosis

Amount of Potentially Recruitable Lung (% total lung weight)



Lung computed tomography during a lung recruitment maneuver in patients with acute lung injury

Bugedo G, Bruhn A, Hernández G, Rojas G, Varela C, Tapia JC, Castillo L

Intensive Care Med. 2003 Feb;29(2):218-25

PMID 12536272, <http://www.ncbi.nlm.nih.gov/pubmed/12536272>

Design	Prospective interventional study: Staircase RM (recruitment maneuver) up to 30-40 cmH ₂ O
Patients	10 ARDS patients
Objectives	Assess the acute effect of a RM on lung morphology
Main Results	Poorly aerated and non-aerated tissue at PEEP 10 cmH ₂ O = 60 ±9% of lung parenchyma, 1 ±2% was hyperinflated. Increasing PEEP to 20 and 30 cmH ₂ O, compared to PEEP 10 cmH ₂ O, decreased poorly aerated and non-aerated tissue by 16 ±28% and 33 ±14%. Hyperinflated tissue increased up to 3 ±4% with PEEP 30 cmH ₂ O.
Conclusion	RM recruited collapsed alveoli without inducing too much hyperinflation

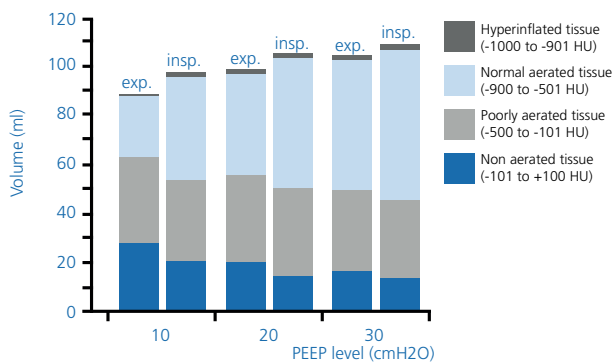


Figure 13: Increasing PEEP, decreased the non aerated tissue without increase of hyperinflated tissue

Effects of recruiting maneuvers in patients with acute respiratory distress syndrome ventilated with protective ventilatory strategy

Grasso S, Mascia L, Del Turco M, Malacarne P, Giunta F, Brochard L, Slutsky AS, Marco Ranieri V

Anesthesiology. 2002 Apr;96(4):795-802

PMID 11964585, <http://www.ncbi.nlm.nih.gov/pubmed/11964585>

Design	Prospective interventional study: 40 seconds sustained inflation at 40 cmH2O
Patients	22 ARDS patients. Patients were classified as responders and nonresponders on the occurrence of a 50% increase in PaO ₂ /FiO ₂
Objectives	Assess the influence of the elastic properties of the lung and chest wall on the effectiveness of a RM (recruitment maneuver).
Main Results	RM increased PaO ₂ /FiO ₂ by 20 ±3% in nonresponders (n = 11) and by 175 ±23% (n = 11) in responders. EI (elastance of lung) and Ecw (elastance of chest wall) were higher in nonresponders. Cardiac output and mean arterial pressure decreased by 31 ±2 and 19 ±3% in nonresponders and by 2 ±1 and 2 ±1% in responders.
Conclusion	RM improved oxygenation and was well tolerated in patients who do not have impairment of chest wall mechanics

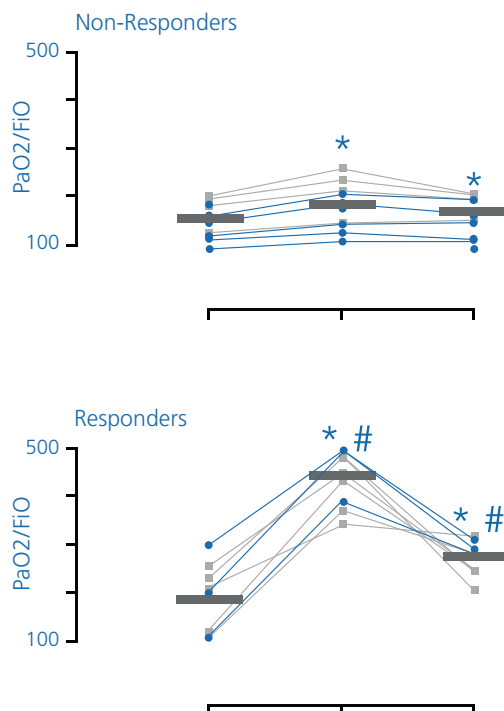


Figure 14: Some patients increased SpO₂ during RM, they were called "Responders" and the others didn't increase SpO₂, the "Non-responders"

Effect of Intraoperative High Positive End-Expiratory Pressure (PEEP) With Recruitment Maneuvers vs Low PEEP on Postoperative Pulmonary Complications in Obese Patients: A Randomized Clinical Trial

Writing Committee for the PROBESE Collaborative Group of the PROtective Ventilation Network (PROVENet) for the Clinical Trial Network of the European Society of Anaesthesiology, Bluth T, Serpa Neto A, Schultz MJ, Pelosi P, Gama de Abreu M

JAMA. 2019 Jun 18;321(23):2292-2305

PMID 31157366, <http://www.ncbi.nlm.nih.gov/pubmed/31157366>

Design	Multicenter randomized controlled trial: 77 sites, 23 countries
Patients	2013 adults with BMI of 35 or greater and substantial risk for postoperative pulmonary complications who were undergoing noncardiac, nonneurological surgery under general anesthesia
Objectives	Determine whether a higher level of PEEP (PEEP = 12 cmH ₂ O) with alveolar recruitment maneuvers (stepwise increase of tidal volume and eventually PEEP) decreases postoperative pulmonary complications compared with a lower level of PEEP (4 cmH ₂ O).
Main Results	The primary outcome was a composite of pulmonary complications within the first 5 postoperative days, including respiratory failure, acute respiratory distress syndrome, bronchospasm, new pulmonary infiltrates, pulmonary infection, aspiration pneumonitis, pleural effusion, atelectasis, cardiopulmonary edema, and pneumothorax. It occurred in 21.3% in the high level of PEEP group compared with 23.6% in the low level of PEEP group ($p = 0.23$).
Conclusion	Among obese patients undergoing surgery under general anesthesia, an intraoperative mechanical ventilation strategy with a high level of PEEP and recruitment maneuvers without prior recruitability assessment did not reduce postoperative pulmonary complications.
Comment	Recruitment potential was not assessed before performing the recruitment maneuvers.

Recruitment maneuvers: using transpulmonary pressure to help Goldilocks

Baedorf Kassiss E, Loring S, Talmor D.

Intensive Care Med. 2017 Aug;43(8):1162-1163

PMID 28386726, <http://www.ncbi.nlm.nih.gov/pubmed/28386726>

Design	Post hoc analysis of EPVent study
Patients	28 patients
Objectives	Measure the change in lung elastance during recruitment: A decrease in elastance of lung (negative ΔEL) was considered evidence of recruitment and an increase in elastance of lung (positive ΔEL) evidence of overdistension.
Main Results	Recruited volume was dependent on transpulmonary pressure during the maneuver and inversely dependent on ΔEL (elastance of lung): - ΔEL was positive during recruitment in patients with PL,RM (peak transpulmonary pressure) ≥ 20 cmH ₂ O - ΔEL was negative when PL,RM was between 10 and 20 cmH ₂ O - ΔEL was negligible in patients with PL,RM below 10 cmH ₂ O
Conclusion	The optimal peak transpulmonary pressure during recruitment, where pressure expands the lung, optimizes elastance, and avoids overdistension, is between 10 and 20 cmH ₂ O.
Comment	Transpulmonary pressure helps to determine the pressure that is efficient and safe to perform a recruitment maneuver.

Impact of recruitment on static and dynamic lung strain in acute respiratory distress syndrome

García-Prieto E, López-Aguilar J, Parra-Ruiz D, Amado-Rodríguez L, López-Alonso I, Blázquez-Prieto J, Blanch L, Albaiceta GM

Anesthesiology. 2016 Feb;124(2):443-52

PMID 26569171, <http://www.ncbi.nlm.nih.gov/pubmed/26569171>

Design	Animal study and prospective physiological study
Patients	6 oleic acid-injured pigs and 6 patients with moderate-to-severe ARDS
Objectives	Clarify the role of recruitment in strain measurements defined as the ratio between end-inspiratory volume and functional residual capacity
Main Results	In the animal model, recruitment caused a significant decrease in dynamic strain ($p < 0.01$), while increasing the static component. In patients, total strain remained constant for the three ventilatory settings. Increases in tidal volume had no significant effects. Increasing PEEP constantly decreased dynamic strain ($p < 0.05$) and increased static strain ($p < 0.05$). The changes in dynamic and total strain among patients were correlated to the amount of recruited volume.
Conclusion	Recruitment causes a shift from dynamic to static strain in early acute respiratory distress syndrome

Volume delivered during recruitment maneuver predicts lung stress in acute respiratory distress syndrome

Beitler JR, Majumdar R, Hubmayr RD, Malhotra A, Thompson BT, Owens RL, Loring SH, Talmor D

Crit Care Med. 2016 Jan;44(1):91-9

PMID 26474111, <http://www.ncbi.nlm.nih.gov/pubmed/26474111>

Design	EPVent substudy
Patients	42 ARDS patients
Objectives	Determine whether the volume delivered during a recruitment maneuver (VRM), consisting of sustained inflation at 40 cmH ₂ O for 30 s, is inversely associated with lung stress and mortality in acute respiratory distress syndrome
Main Results	VRM ranged between 7.4 and 34.7 ml/kg predicted body weight. Lower VRM predicted high end-inspiratory and tidal lung stress. Low VRM was also associated with an increased risk of death.
Conclusion	Low VRM predicted high lung stress and may predict risk of death in patients with acute respiratory distress syndrome
Comment	This study used VRM to assess the maximum size of the aerated lung to establish the potential recruitability

Sigh in supine and prone position during acute respiratory distress syndrome

Pelosi P, Bottino N, Chiumello D, Caironi P, Panigada M, Gamberoni C, Colombo G, Bigatello LM, Gattinoni L

Am J Respir Crit Care Med. 2003 Feb 15;167(4):521-7

PMID 12493644, <http://www.ncbi.nlm.nih.gov/pubmed/12493644>

Design	Prospective interventional study: 3 sighs/min
Patients	10 early ARDS patients
Objectives	Evaluate recruitment in supine and prone position
Main Results	Sighs increased PaO ₂ in both supine and prone position. The highest values of PaO ₂ and EELV (end-expiratory lung volume) occurred with the addition of sighs in prone and remained significantly elevated 1 hour after discontinuation of the sighs. The increase in PaO ₂ associated with the sighs, both in supine and prone position, correlated linearly with the increase of EELV.
Conclusion	RM (recruitment maneuver) during ventilation in the prone position provided optimal lung recruitment

Maximal Recruitment Open Lung Ventilation in Acute Respiratory Distress Syndrome (PHARLAP): A Phase II, Multicenter, Randomized, Controlled Trial

Hodgson CL, Cooper DJ, Arabi Y, King V, Bersten A, Bihari S, Brickell K, Davies A, Fahey C, Fraser J, McGuinness S, Murray L, Parke R, Paul E, Tuxen D, Vallance S, Young M, Nichol A; PHARLAP Study Investigators and the ANZICS Clinical Trials Group

Am J Respir Crit Care Med. 2019 Jul 29

PMID 31356105, <http://www.ncbi.nlm.nih.gov/pubmed/31356105>

Design	Phase II multicenter, randomized, controlled trial: Patients received either maximal lung recruitment, titrated positive end-expiratory pressure (PEEP) and tidal volume limitation, or control 'protective' ventilation: 35 ICUs in 5 countries
Patients	115 patients with acute respiratory distress syndrome (ARDS) (planned 340 patients) between October 2012 and September 2017
Objectives	Determine whether a maximal lung recruitment strategy reduces ventilator-free days in ARDS patients
Main Results	Enrolment was halted on 2 October, 2017 following publication of the Alveolar Recruitment Trial, when 115 of a planned 340 patients had been randomized. There were no differences in ventilator-free days, mortality, or barotrauma between groups. In the intervention group there was reduced use of hypoxemic adjuvant therapies (inhaled nitric oxide, extracorporeal membrane oxygenation, prone position),
Conclusion	Maximal lung recruitment without prior assessment of recruitability did not reduce the duration of ventilator-free days or mortality.
Comment	Recruitment potential was not assessed before the recruitment maneuvers were performed. The study was stopped early and enrolment was very slow.

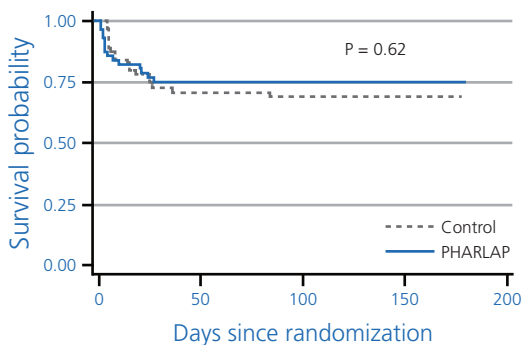


Figure 15: Kaplan-Meier curve shows no difference in survival between the groups.

Opening pressures and atelectrauma in acute respiratory distress syndrome

Cressoni M, Chiumello D, Algieri I, Brioni M, Chiurazzi C, Colombo A, Colombo A, Crimella F, Guanziroli M, Tomic I, Tonetti T, Luca Vergani G, Carlesso E, Gasparovic V, Gattinoni L

Intensive Care Med. 2017 May;43(5):603-611

PMID 28283699, <http://www.ncbi.nlm.nih.gov/pubmed/28283699>

Design	Bicenter prospective study
Patients	33 ARDS: 5 mild, 10 moderate, 9 severe without ECMO, 9 severe with ECMO
Objectives	Measure the recruitment at different PEEP and plateau pressures
Main Results	The ratio of lung tissue which opened between 30 and 45 cmH ₂ O increased with the severity of the disease between 10 ± 29 and 185 ± 134 g ($p < 0.05$). The intratidal collapses were similar at a PEEP level of 5 cmH ₂ O and 15 cmH ₂ O, regardless of the severity. Increasing the applied airway pressure up to 45 cmH ₂ O decreased the lung inhomogeneity in mild and moderate ARDS, but not in severe ARDS.
Conclusion	Patients with the most severe ARDS are the most recruitable. For effective recruitment, airway pressures higher than 30 cmH ₂ O are required.

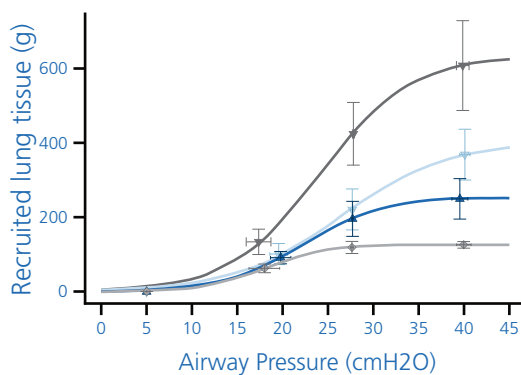


Figure 16: Light gray: mild ARDS; Dark blue: moderate ARDS; Light blue: severe ARDS without ECMO, Dark gray: severe ARDS with ECMO. The more severe the ARDS, the more recruitable the lungs

A positive response to a recruitment maneuver with PEEP titration in patients with ARDS, regardless of transient oxygen desaturation during the maneuver

Hodgson CL, Tuxen DV, Bailey MJ, Holland AE, Keating JL, Pilcher D, Thomson KR, Varma D
J Intensive Care Med. 2011 Jan-Feb;26(1):41-9
PMID 21262752, <http://www.ncbi.nlm.nih.gov/pubmed/21262752>

Design	Prospective interventional study: Staircase RM (recruitment maneuver) up to 40 cmH2O
Patients	20 early ALI patients
Objectives	Evaluate the safety and the respiratory and hemodynamic effects of a staircase RM
Main Results	There were significant improvements in shunt fraction, oxygen saturation (93% $\pm$ 2% to 97% $\pm$ 3%), PaO2, PaO2/FiO2, Crs (compliance of respiratory system), and chest x-ray after the RM. 80% of the patients responded and the response was maintained at 1 hour. 8 patients desaturated 6% $\pm$ 3% in SpO2 during the RM but 5 of those improved SpO2 relative to baseline by the end of the RM.
Conclusion	Most patients with early ALI responded to the RM. Desaturation during the RM did not indicate a failed response 1 h later.

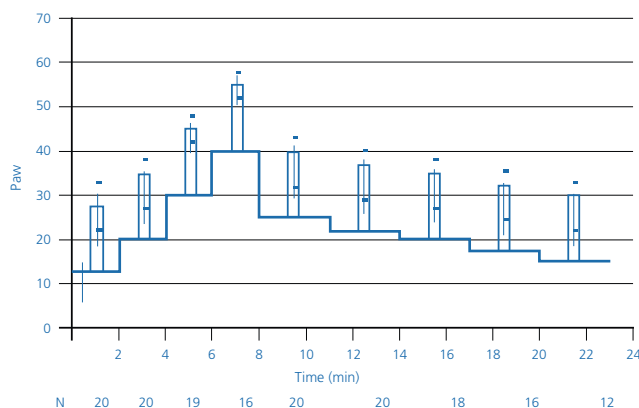


Figure 17: Staircase recruitment maneuver protocol: Increase of PEEP by 10 cmH2O to 40cmH2O, step = 2min; decrease by 2,5 cmH2O, step = 3 min until SpO2 decrease

Safety and efficacy of a sustained inflation for alveolar recruitment in adults with respiratory failure

Lapinsky SE, Aubin M, Mehta S, Boiteau P, Slutsky AS

Intensive Care Med. 1999 Nov;25(11):1297-301

PMID 10654217, <http://www.ncbi.nlm.nih.gov/pubmed/10654217>

Design	Prospective interventional study: 20 seconds sustained inflation at 30 to 45 cmH ₂ O
Patients	14 patients with hypoxemic respiratory failure
Objectives	Assess the safety and efficacy of a 20 second sustained inflation
Main Results	Significant improvement in oxygenation occurred in the majority of patients within 10 min. The mean SpO ₂ improved from 87 ±5 to 94 ±2%. Hypotension and mild oxygen desaturation occurred in some patients during the 20-s inflation, reversing rapidly after inflation was terminated.
Conclusion	Sustained inflation is a safe, clinically applicable RM (recruitment maneuver) that improves oxygenation

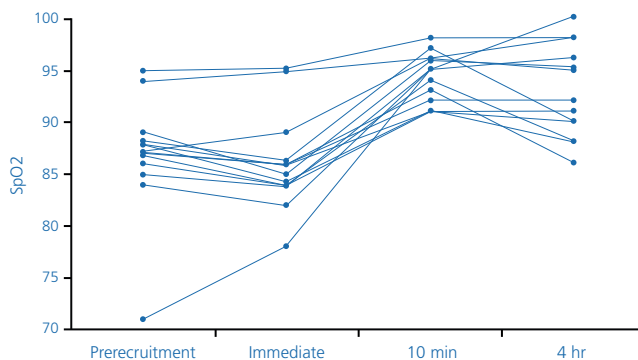


Figure 18: SpO₂ increased during the RM and remained higher than baseline after the RM

Changes in shunt, ventilation/perfusion mismatch, and lung aeration with PEEP in patients with ARDS: a prospective single-arm interventional study

Karbing DS, Panigada M, Bottino N, Spinelli E, Protti A, Rees SE, Gattinoni L

Crit Care. 2020 Mar 23;24(1):111

PMID 32293506, <http://www.ncbi.nlm.nih.gov/pubmed/32293506>

Design	Preliminary study: patients were subjected to recruitment maneuvers (90 s in pressure-control mode (PCV) with plateau pressure (Pplat) 45 cmH ₂ O) followed by setting PEEP at 5 and then either 15 or 20 cmH ₂ O
Patients	12 ARDS patients
Objectives	Investigate the association between changes in shunt, low and high ventilation/perfusion (V/Q) mismatch, and computed tomography-measured lung aeration following an increase in PEEP in patients with ARDS
Main Results	Increasing PEEP resulted in reduced values of pulmonary shunt and the percentage of non-aerated tissue, and an increased percentage of normally aerated tissue ($p < 0.05$). Changes in shunt and normally aerated tissue were correlated. Three distinct responses to increase in PEEP were observed in values of shunt and V/Q mismatch: a beneficial response in seven patients, where shunt decreased without increasing high V/Q; a detrimental response in four patients where both shunt and high V/Q increased; and a detrimental response in one patient with reduced shunt but increased high V/Q mismatch. Non-aerated tissue decreased with increased PEEP in all patients, and hyperinflated tissue increased only in patients with a detrimental response in shunt and V/Q mismatch.
Conclusion	Improved lung aeration following an increase in PEEP is not always consistent with reduced shunt and V/Q mismatch. Poorly matched redistribution of ventilation and perfusion between dependent and non-dependent regions of the lung may explain why patients showed detrimental changes in shunt and V/Q mismatch on increase in PEEP despite improved aeration.

Bedside assessment of the effects of positive end-expiratory pressure on lung inflation and recruitment by the helium dilution technique and electrical impedance tomography

Mauri T, Eronia N, Turrini C, Battistini M, Grasselli G, Rona R, Volta CA, Bellani G, Pesenti A
Intensive Care Med. 2016 Oct;42(10):1576-87
PMID 27518321, <http://www.ncbi.nlm.nih.gov/pubmed/27518321>

Design	Prospective randomized crossover study
Patients	20 patients; 12 with acute hypoxemic respiratory failure and 8 with acute ARDS
Objectives	Measure PEEP-related lung volume changes by EIT (electrical impedance tomography) and by the helium dilution technique
Main Results	PEEP-induced changes in lung inflation and recruitment measured by electrical impedance tomography and helium dilution showed close correlation ($r^2=0.78$, $p<0.001$ and $r^2=0.68$, $p<0.001$, respectively) but with relatively variable limits of agreement. At higher PEEP, recruitment was evident in all lung regions ($p<0.01$) and heterogeneity of tidal ventilation distribution was reduced by increased tidal volume distending the dependent lung ($p<0.001$); in the non-dependent lung, compliance decreased ($p<0.001$) and tidal hyperinflation significantly increased ($p<0.001$). In the subgroup of ARDS patients tidal hyperinflation in the dependent lung regions decreased at higher PEEP ($p=0.05$), probably indicating higher potential for recruitment.
Conclusion	A high level of PEEP exerts mixed effects on the regional determinants of VILI (ventilator- induced lung injury)

Lung recruitment assessed by respiratory mechanics and computed tomography in patients with acute respiratory distress syndrome. What is the relationship?

Chiumello D, Marino A, Brioni M, Cigada I, Menga F, Colombo A, Crimella F, Algieri I, Cressoni M, Carlesso E, Gattinoni L.

Am J Respir Crit Care Med. 2016 Jun 1;193(11):1254-63

PMID 26699672, <http://www.ncbi.nlm.nih.gov/pubmed/26699672>

Design	Prospective interventional study
Patients	22 ARDS patients
Objectives	Determine recruitment measured by respiratory mechanics (PV curve and compliance) is comparable with recruitment measured by computed tomography
Main Results	Recruitment measured by PV curve was $54 \pm 28\%$ and $39 \pm 25\%$ using compliance of the gas volume at 5 cmH ₂ O of PEEP. Recruitment measured by CT scan as not inflated tissue was $5 \pm 5\%$ and $6 \pm 6\%$ if we consider not and poorly inflated tissue, on the total lung tissue.
Conclusion	Respiratory mechanics and CT measured two different entities. The respiratory mechanics-based methods included gas entering in already open pulmonary units that improve their mechanical properties (used to assess the overall improvement of inflation). The CT scan measured the amount of collapsed tissue that regains inflation.

Dynamics of end expiratory lung volume after changing positive end-expiratory pressure in acute respiratory distress syndrome patients

Garnero A, Tuxen D, Corno G, Durand-Gasselin J, Hodgson C, Arnal JM

Crit Care. 2015 Sep 18;19:340

PMID 26383835, <http://www.ncbi.nlm.nih.gov/pubmed/26383835>

Design	Prospective interventional study: Staircase RM (recruitment maneuver) up to 40 cmH2O
Patients	26 early onset moderate to severe ARDS patients
Objectives	Measure the dynamics of end-expiratory lung volume changes during an increase and decrease in PEEP between 5 and 40 cmH2O by steps of 5 cmH2O to determine the optimal duration for each step during an SRM
Main Results	During the increase in PEEP, the expected increased volume (respiratory system compliance by the increase in pressure) was achieved within 2 [2-2] breaths and 95% of the additional increased volume (total end expiratory volume change minus expected increased volume) was achieved within 13 [6–16] breaths. During the decrease in PEEP, the expected decreased volume was achieved within 1 [1-1] breath, and 95 % of the additional decreased volume was achieved within 8 [2-15] breaths.
Conclusion	In early ARDS, most of the end expiratory volume change occurred within the first minute

Acute physiologic effects of a stepwise recruitment maneuver in acute respiratory distress syndrome

Morán I, Blanch L, Fernández R, Fernández-Mondéjar E, Zavala E, Mancebo J

Minerva Anestesiol. 2011 Dec;77(12):1167-75

PMID 21623343, <http://www.ncbi.nlm.nih.gov/pubmed/21623343>

Design	Prospective interventional study: Staircase RM (recruitment maneuver) up to 40 cmH2O
Patients	13 early ARDS patients
Objectives	Assess the clinical impact of RM
Main Results	2 h after the RM, the PaO ₂ /FiO ₂ was higher than at baseline (187 ±102 versus 339 ±136 mmHg). The RM was discontinued due to severe complications in four patients: 3 for CO ₂ decrease, 1 for hypotension, 1 for supraventricular tachycardia.
Conclusion	Staircase RM should be applied carefully and closely monitored

Acute hemodynamic effects of recruitment maneuvers in patients with acute respiratory distress syndrome

Park KJ, Oh YJ, Chang HJ, Sheen SS, Choi J, Lee KS, Park JH, Hwang SC

J Intensive Care Med. 2009 Nov-Dec; 24(6):376-82

PMID 19846416, <http://www.ncbi.nlm.nih.gov/pubmed/19846416>

Design	Prospective interventional study: 30 seconds sustained inflation at 40 cmH ₂ O
Patients	22 ARDS patients
Objectives	Evaluated circulatory and cardiac changes during RM (recruitment maneuver)
Main Results	Mean, systolic, and diastolic blood pressure decreased at 20 and 30 seconds during RM (mean blood pressure: 92 ±12 at baseline to 83 ±18 mmHg at the end of the RM) and subsequently recovered. Heart rate decreased at 10 and 20 seconds during the RM, and tended to increase afterward. Both ventricular dimensions decreased significantly during the RM. The left ventricular ejection fraction and peak velocity of the left ventricle during systole remained stable. The fractional changes in mean BP (blood pressure) and left ventricular end-diastolic dimension were correlated.
Conclusion	A transient decrease in mean BP was observed during the RM, and its degree was correlated with the preload decrease

Physiological effects of different recruitment maneuvers in a pig model of ARDS

Xia F, Pan C, Wang L, Liu L, Liu S, Guo F, Yang Y, Huang Y

BMC Anesthesiol. 2020 Oct 21;20(1):266

PMID 33087066, <http://www.ncbi.nlm.nih.gov/pubmed/33087066>

Design	Experimental study
Patients	10 healthy male pigs with surfactant depletion induced ARDS
Objectives	Investigate by means of electrical impedance tomography (EIT) the physiological effects of different recruitment maneuvers (sustained inflation, increments of PEEP, and pressure-controlled ventilation) for alveolar recruitment in a pig model of ARDS
Main Results	PaO ₂ , P/F, and compliance were significantly improved after recruitment with sustained inflation, increments of PEEP, or PCV ($p < 0.05$), and there were no significant differences between maneuvers. Global inhomogeneity index (ΔGI) significantly decreased after recruitment with sustained inflation, increments of PEEP, or PCV. The decrease in global inhomogeneity index was significantly greater after recruitment with increments of PEEP compared to sustained inflation ($p = 0.023$), but there was no significant difference in ΔGI between increments of PEEP and PCV, or between sustained inflation and PCV.
Conclusion	Sustained inflation, increments of PEEP, and PCV increased oxygenation and compliance, and decreased inhomogeneous gas distribution in ARDS pigs

Intercomparison of recruitment maneuver efficacy in three models of acute lung injury

Lim SC, Adams AB, Simonson DA, Dries DJ, Broccard AF, Hotchkiss JR, Marini JJ

Crit Care Med. 2004 Dec;32(12):2371-7

PMID 15599138, <http://www.ncbi.nlm.nih.gov/pubmed/15599138>

Design	Animal study: 40 seconds sustained inflation at 45 cmH ₂ O, staircase RM (recruitment maneuver) and PC
Patients	28 pigs with VILI, oleic acid injury or pneumococcal pneumonia
Objectives	Evaluate the hemodynamic consequence of 3 RM techniques
Main Results	PC caused a lasting increase of PaO ₂ in the VILI model, but in oleic acid injury and pneumococcal pneumonia, there were no differences for any RM technique.
Conclusion	The 3 RM techniques were equivalent in terms of oxygenation

Pediatric patients

Respiratory and hemodynamic effects of a stepwise lung recruitment maneuver in pediatric ARDS: a feasibility study

Cruces P, Donoso A, Valenzuela J, Díaz F

Pediatr Pulmonol. 2013 Nov;48(11):1135-43

PMID 23255291, <http://www.ncbi.nlm.nih.gov/pubmed/23255291>

Design	Prospective interventional study: Staircase RM (recruitment maneuver) up to 25 cmH2O
Patients	25 pediatric early ARDS patients, age = 5 [1-16] months
Objectives	Assess the effects on gas exchange and lung mechanics of RM in pediatric ARDS patients
Main Results	30 RM were performed, with all completed successfully. No airleaks developed. Mild hypotension was detected during 4 RM. Following RM, Crs (compliance of respiratory system), and PaO ₂ /FiO ₂ increased without changes in PaCO ₂ . Oxygenation improved at 12 and 24 hr. The 28-day mortality rate was 16%.
Conclusion	RM were safe, well tolerated and improved lung function in children with ARDS

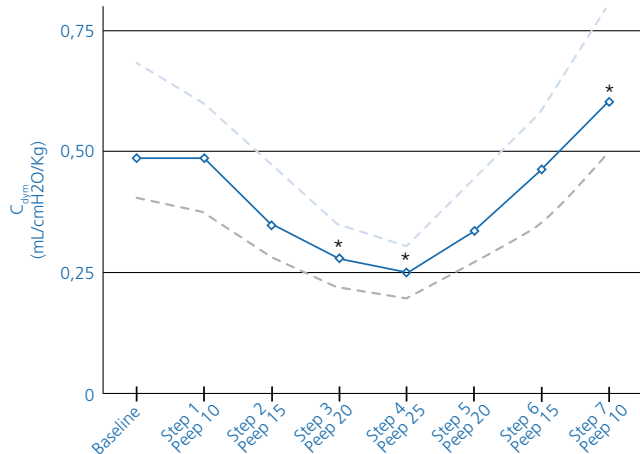


Figure 19: Compliance decreased at high level of PEEP during RM but increase during the decremental PEEP trial and was higher at the end of the protocol than at baseline

The safety and efficacy of sustained inflations as a lung recruitment maneuver in pediatric intensive care unit patients

Duff JP, Rosychuk RJ, Joffe AR

Intensive Care Med. 2007 Oct;33(10):1778-86

PMID 17607560, <http://www.ncbi.nlm.nih.gov/pubmed/17607560>

Design	Prospective interventional study: 15-20 seconds sustained inflation at 30-40 cmH ₂ O was performed following a ventilator disconnection, suctioning, hypoxemia, or routinely every 12 h
Patients	32 pediatric patients aged from 11 days to 14 years
Objectives	Assess the safety and efficacy of RM (recruitment maneuver) in pediatric patients
Main Results	7/93 RM (7.5%) were interrupted for patient agitation, and 2/93 (2.2%) for transient bradycardia. There was no change in systolic blood pressure, heart rate, or SpO ₂ from pre-RM to post-RM, and there were no air leaks. In 3 patients with altered intracranial compliance, 3/8 RM were associated with a spike of intracranial pressure. There was a sustained significant decrease in FiO ₂ by 6% lasting up to 6 h post-RM.
Conclusion	RM was safe in pediatric patients

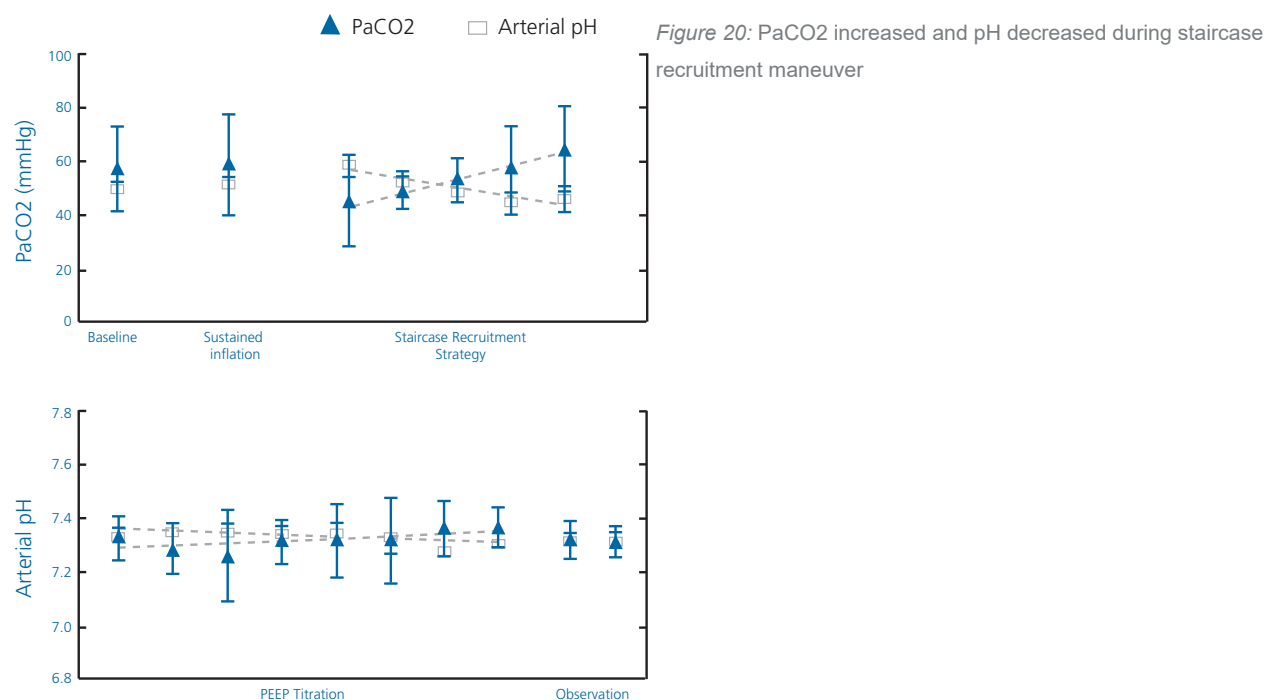
Comparison of 2 lung recruitment strategies in children with acute lung injury

Kheir JN, Walsh BK, Smallwood CD, Rettig JS, Thompson JE, Gómez-Laberge C, Wolf GK, Arnold JH

Respir Care. 2013 Aug;58(8):1280-90

PMID 23232733, <http://www.ncbi.nlm.nih.gov/pubmed/23232733>

Design	Prospective, non-randomized, crossover pilot study: 40 seconds sustained inflation at 40 cmH ₂ O and staircase RM (recruitment maneuver) up to 35 cmH ₂ O
Patients	10 pediatric ALI patients from 4 years to 17 years
Objectives	Compare the acute effects of 2 RM strategies
Main Results	Both methods were effective in raising PaO ₂ and FRC (functional residual capacity). Sustained inflation was associated with temporary desaturation. During the staircase RM, dead-space and PaCO ₂ increased, CO ₂ elimination and Crs decreased.
Conclusion	Both methods were effective in raising PaO ₂ but staircase RM required caution about CO ₂



Lung aeration changes after lung recruitment in children with acute lung injury: a feasibility study

Boriosi JP, Cohen RA, Summers E, Sapru A, Hanson JH, Gildengorin G, Newman V, Flori HR

Pediatr Pulmonol. 2012 Aug;47(8):771-9

PMID 22298419, <http://www.ncbi.nlm.nih.gov/pubmed/22298419>

Design	Case series: Staircase RM (recruitment maneuver)
Patients	6 pediatric ALI patients aged from 1 month to 15 years
Objectives	Describe CT-scan lung aeration changes and gas exchange after RM in pediatric ALI patients
Main Results	There was a variable increase in aerated and poorly aerated lung after the RM ranging from 3% to 72% (20% [6-47]). All patients had improvement in PaO ₂ /FiO ₂ after the RM (14% [8-72]. 4/6 had a decrease in PaCO ₂ . One subject had transient hypercapnia during the RM and this correlated with the smallest increase in aerated lung. All patients tolerated the RM without hemodynamic compromise, barotrauma, hypoxemia, or dysrhythmias.
Conclusion	Lung recruitment resulted in improved lung aeration as detected by lung tomography, accompanied by improvements in oxygenation and ventilation

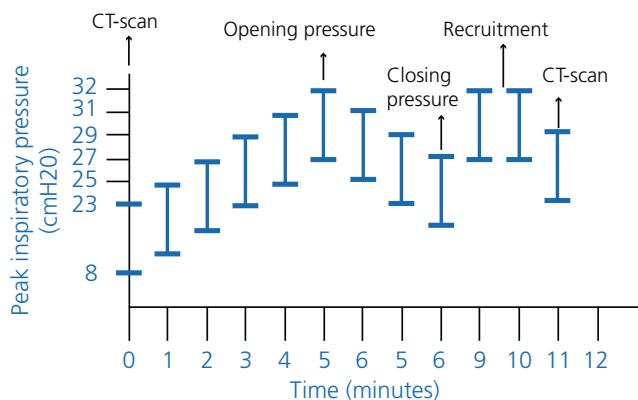


Figure 21: Pediatric staircase recruitment maneuver protocol. PEEP is increased by 2 cmH₂O every minute to critical opening pressure (PEEP associated with the highest Crs) or Pinsp = 45 cmH₂O. Then PEEP is decreased by 2 cmH₂O every minute to critical opening pressure (PEEP associated with the highest Crs). After 2 min is spent at the critical opening pressure and PEEP is settled at critical opening pressure +2 cmH₂O.

Additional files

Monitoring lung recruitment

Cammarota G, Vaschetto R, Vetrugno L, Maggiore SM
Curr Opin Crit Care. 2024 Jun 1;30(3):268-274
PMID 38690956, <http://www.ncbi.nlm.nih.gov/pubmed/38690956>

Design	Review
Objectives	Explore lung recruitment monitoring, covering techniques, challenges, and future perspectives
Conclusion	Monitoring lung recruitment is a crucial component of managing patients with severe lung conditions, within the framework of a personalized ventilatory strategy.

Recruitment maneuvers in patients undergoing thoracic surgery: a meta-analysis

Hu MC, Yang YL, Chen TT, Chen JT, Tiong TY, Tam KW
Gen Thorac Cardiovasc Surg. 2021 Jun 21
PMID 34152550, <http://www.ncbi.nlm.nih.gov/pubmed/34152550>

Design	Meta-analysis
Patients	6 RCTs involving 526 patients
Objectives	Evaluate the effectiveness and safety of recruitment maneuvers in patients undergoing thoracic surgery
Main Results	Patients receiving a recruitment maneuver exhibited a significant decrease in intrapulmonary shunt fraction, improved static lung compliance, and PaO ₂ /FIO ₂ ratio, without a significant difference in mean arterial pressure
Conclusion	Recruitment maneuvers may be a viable treatment for reducing intra-pulmonary shunt and improving static lung compliance and PaO ₂ /FIO ₂ ratio without the disturbance of hemodynamics in patients undergoing thoracic surgery.

Recruitment maneuvers to reduce pulmonary atelectasis after cardiac surgery: A meta-analysis of randomized trials

Hu MC, Yang YL, Chen TT, Lee CI, Tam KW

J Thorac Cardiovasc Surg. 2020 Nov 26:S0022-5223(20)33105-6

PMID 33341273, <http://www.ncbi.nlm.nih.gov/pubmed/33341273>

Design	Meta-analysis
Patients	16 trials involving 1455 patients
Objectives	Evaluate if recruitment maneuvers may relieve pulmonary atelectasis in patients undergoing cardiac surgery
Main Results	As compared with those who received conventional mechanical ventilation, patients receiving recruitment maneuvers had a reduced incidence of pulmonary atelectasis, reduced incidence of hypoxic events, reduced incidence of pneumonia, and improved Pao ₂ /Fio ₂ ratio without disturbing the cardiac index. The incidence of pneumothorax was not different between the groups.
Conclusion	Recruitment maneuvers may reduce postoperative pulmonary atelectasis, hypoxic events, and pneumonia, and improve PaO ₂ /FiO ₂ ratios without hemodynamic disturbance in patients undergoing cardiac surgery.

The Nature of Recruitment and Derecruitment and its Implications for Management of ARDS

Kallet RH, Lipnick MS, Burns G

Respir Care. 2020 Oct 13;respcare.08280

PMID 33051254, <http://www.ncbi.nlm.nih.gov/pubmed/33051254>

Design	Review
Objectives	This narrative review examines the evidence used to design RM (recruitment maneuver) strategies, with the radiologic, rheologic, and histopathologic evidence regarding the nature of lung injury, the phenomena of recruitment and derecruitment as it informs our perceptions of recruitment potential in ARDS. Major clinical trial data are examined to assess the practical necessity of RM in ARDS, and whether a subset of cases might benefit from pursuing RM therapy.
Conclusion	A less radical approach to RM is offered that might achieve the goals of RM with less risk of harm.

Recruitment maneuvers and higher PEEP, the so-called open lung concept, in patients with ARDS

Van der Zee P, Gommers D.

Crit Care. 2019 Mar 9;23(1):73.

PMID 30850004, <http://www.ncbi.nlm.nih.gov/pubmed/30850004>

Design	Review
Objectives	Discuss the pathophysiology of ARDS and VILI (ventilator-induced lung injury), limitations and indications of the open lung concept, bedside monitoring to guide the open lung concept
Conclusion	Open lung concept should be applied in patients with severe ARDS with refractory hypoxemia, but only if a patient is a responder to recruitment

Lung recruitment maneuvers for adult patients with acute respiratory distress syndrome. A systematic review and meta-analysis.

Goligher EC, Hodgson CL, Adhikari NKJ, Meade MO, Wunsch H, Uleryk E, Gajic O, Amato MPB, Ferguson ND, Rubenfeld GD, Fan E

Am Thorac Soc. 2017 Oct;14(Supplement_4):S304-S311

PMID 29043837, <http://www.ncbi.nlm.nih.gov/pubmed/29043837>

Design	Systematic review and meta-analysis
Objectives	Summarize the current evidence in support of the use of RM (recruitment maneuver) in ARDS patients
Main Results	Meta-analysis of six trials suggested a mortality reduction (RR, 0.81; 95% CI, 0.69-0.95), an improvement of oxygenation and less frequent requirement for rescue therapy. RM were not associated with an increased rate of barotrauma or with the rate of hemodynamic compromise.
Conclusion	Randomized trials suggest that RM in combination with a higher PEEP ventilation strategy reduce mortality

Assessment of the Effect of Recruitment Maneuver on Lung Aeration Through Imaging Analysis in Invasively Ventilated Patients: A Systematic Review

Pierrakos C, Smit MR, Hagens LA, Heijnen NFL, Hollmann MW, Schultz MJ, Paulus F, Bos LDJ

Front Physiol. 2021 Jun 4;12:666941

PMID 34149448, <http://www.ncbi.nlm.nih.gov/pubmed/34149448>

Design	Systemic review
Patients	20 studies included invasively ventilated patients who received a recruitment maneuver (RM) and in whom re-aeration was examined with CT, EIT, and lung ultrasound (LUS)
Objectives	The amount of re-aerated lung tissue after an RM was highly variable. Imaging findings suggesting a non-focal morphology were associated with higher likelihood of recruitment and lower chance of overdistention than a focal morphology. This was only observed in patients with ARDS. In patients without ARDS, the results were inconclusive.
Conclusion	ARDS patients with non-focal morphology show most re-aeration of previously consolidated lung tissue after RMs.

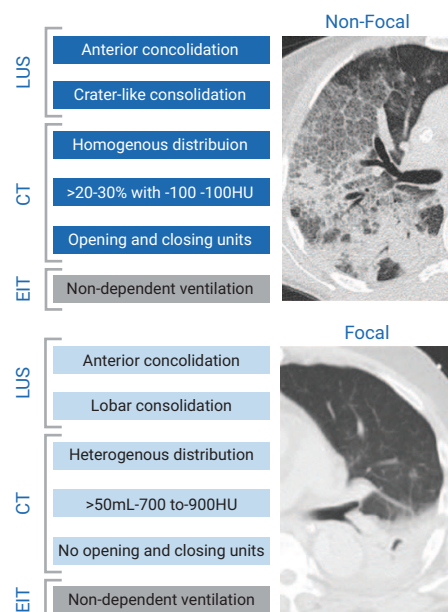


Figure 22: Imaging abnormalities that predicted response to recruitment maneuvers stratified per morphology

Recruitment-to-inflation ratio for bedside PEEP selection in acute respiratory distress syndrome

Rosà T, Bongiovanni F, Michi T, Mastropietro C, Menga LS, DE Pascale G, Antonelli M, Grieco DL
Minerva Anestesiol. 2024 Jul-Aug;90(7-8):694-706
PMID 39021144, <http://www.ncbi.nlm.nih.gov/pubmed/39021144>

Design	Review
Objectives	Discuss the rationale, applications, and limits of the recruitment-to-inflation ratio, providing insights on its clinical use for PEEP selection in moderate-to-severe acute respiratory distress syndrome

Lung Recruitment Maneuvers for ARDS Patients: A Systematic Review and Meta-Analysis

Cui Y, Cao R, Wang Y, Li G
Respiration. 2019 Jul 22:1-13
PMID 31330508, <http://www.ncbi.nlm.nih.gov/pubmed/31330508>

Design	Systematic review and meta-analysis
Objectives	Determine whether lung recruitment maneuvers (LRMs) have benefits on ARDS patients
Conclusion	This meta-analysis showed a significant benefit of LRMs for shortening the length of hospital stay and improving the PaO ₂ /FiO ₂ ratio.

Recruitment maneuvers and PEEP titration

Hess DR

Respir Care. 2015 Nov;60(11):1688-704

PMID 26493593, <http://www.ncbi.nlm.nih.gov/pubmed/26493593>

Design	Review
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Conclusion	Principles and methods for recruitment and PEEP titration
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Lung recruitment in acute respiratory distress syndrome: what is the best strategy?

Keenan JC, Formenti P, Marini JJ

Curr Opin Crit Care. 2014 Feb;20(1):63-8

PMID 24335655, <http://www.ncbi.nlm.nih.gov/pubmed/24335655>

Design	Review
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Conclusion	Why, when and how to perform RM (recruitment maneuver)
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Recruitment maneuvers for acute lung injury: a systematic review

Fan E, Wilcox ME, Brower RG, Stewart TE, Mehta S, Lapinsky SE, Meade MO, Ferguson ND

Am J Respir Crit Care Med. 2008 Dec 1;178(11):1156-63

PMID 18776154, <http://www.ncbi.nlm.nih.gov/pubmed/18776154>

Design	Systematic review
Objectives	Summarize the physiologic effects and adverse events of RM (recruitment maneuver)
Conclusion	Oxygenation was significantly increased after an RM, there were no persistent, clinically significant changes in hemodynamic parameters after an RM. Hypotension and desaturation were the most common adverse events. Serious adverse events (barotrauma [1%] and arrhythmias [1%]) were infrequent.

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