Современный взгляд на рекрутмент-маневр

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08 сентября 2017 года, г. Красноярск

Конфликт интересов

- Drager
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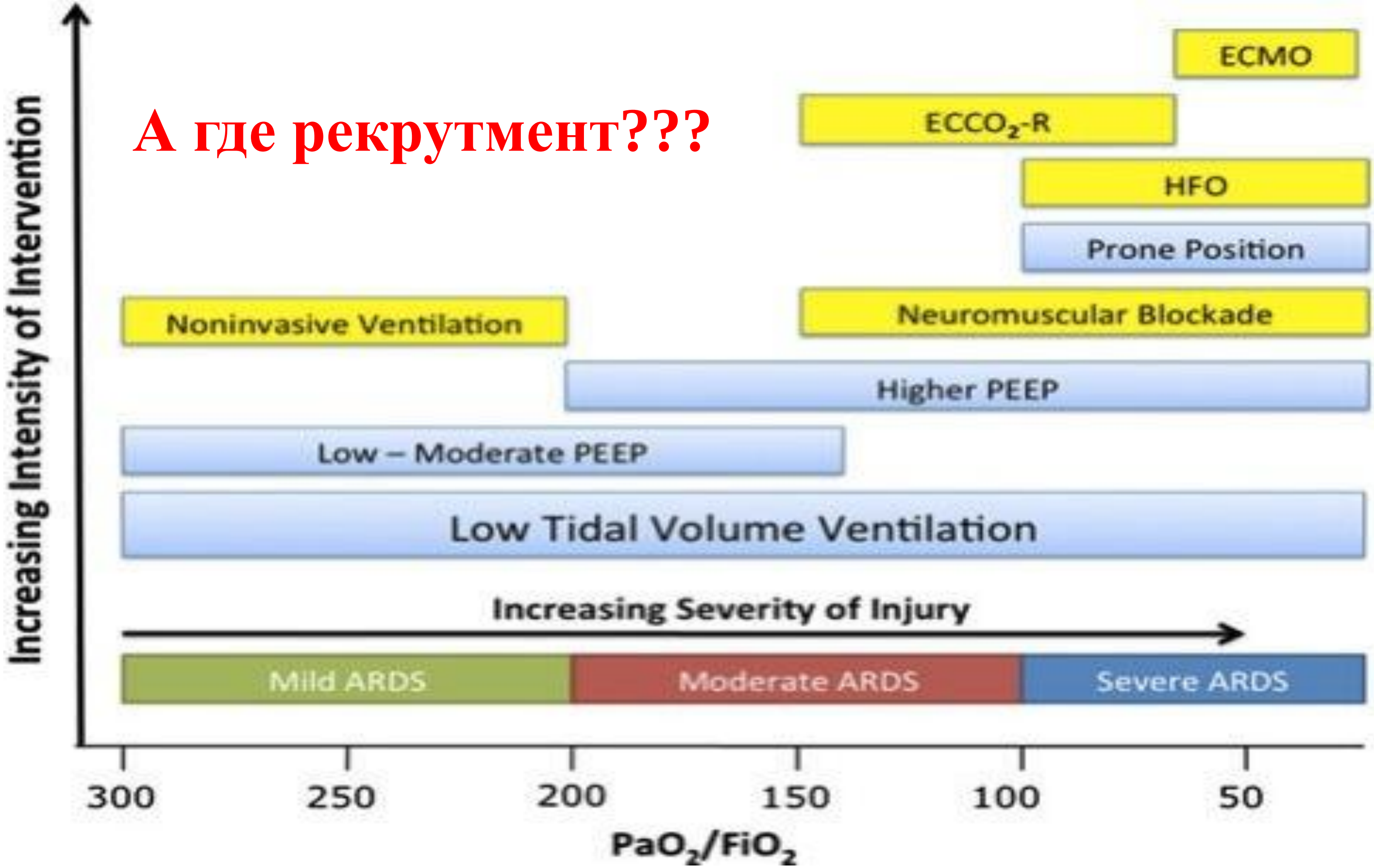
А где рекрутмент???



Intensive Care Med (2012) 38:1573–1582
DOI 10.1007/s00134-012-2682-1

SPECIAL ARTICLE

Niall D. Ferguson
Eddy Fan
Luigi Camporota
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Roy Brower
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The Berlin definition of ARDS: an expanded rationale, justification, and supplementary material

Fig. 1 Aligning Therapeutic Options with The Berlin Definition (adapted from [48] with permission). This figure depicts potential therapeutic options according to the severity of ARDS. Boxes in yellow represent therapies that in the opinion of the panel still require confirmation in prospective clinical trials. This figure is just a model based on currently available information. In the coming years, various aspects of the figure will likely change; proposed cut-offs may move, and some therapies may be found to not be useful, while others may be added

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1. **Recruitment maneuvers** in acute respiratory distress syndrome: The safe way is the best way.
Santos RS, Silva PL, Pelosi P, Rocco PR.
World J Crit Care Med. 2015 Nov 4;4(4):278-86. doi: 10.5492/wjccm.v4.i4.278. eCollection 2015 Nov 4. Review.
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2. Prolonged prone positioning under VV-ECMO is safe and improves oxygenation and respiratory compliance.
Kimmoun A, Roche S, Bridey C, Vanhuyse F, Fay R, Girerd N, Mandry D, Levy B.
Ann Intensive Care. 2015 Dec;5(1):35. doi: 10.1186/s13613-015-0078-4. Epub 2015 Nov 4.
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DOI 10.1007/s00134-015-4070-0

WHAT'S NEW IN INTENSIVE CARE

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Emir Festic

Ventilatory support of patients with sepsis or septic shock in resource-limited settings

Recruitment maneuvers	Use recruitment maneuvers in patients with moderate or severe ARDS (2B), in patients with refractory hypoxemia in whom an ARDS diagnosis cannot be made due to lack of CXR and/or ABG (2D), and only when the staff are trained and experienced in performing these maneuvers (2D); use the simplest maneuver, i.e., 'sustained inflation' (2D); when using recruitment maneuvers, the patient should be closely monitored, preferably by using an arterial line, to promptly detect hemodynamic compromise (2B)
Modes of ventilation	We recommend using 'volume-controlled' modes of ventilation over 'pressure-controlled' modes of ventilation (2D); we cannot recommend on whether assisted ventilation ('support' mode) is preferred over assist ventilation ('controlled' mode) in all patients; use a short course of muscle paralysis (<48 h), and thus controlled ventilation, only in patients with moderate or severe ARDS (2B)

Grading: see online supplement for explanations

CXR chest radiograph, *ABG* arterial blood gas, *ARDS* acute respiratory distress syndrome, *PBW* predicted body weight, *PEEP* positive end expiratory pressure, *NIV* non-invasive ventilation

Intensive Care Med (2013) 39:165–228
DOI 10.1007/s00134-012-2769-8

GUIDELINES

Показания!!!

R. P. Dellinger
Mitchell M. Levy
Andrew Rhodes
Djillali Annane
Herwig Gerlach
Steven M. Opal

Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock, 2012

5. We suggest recruitment maneuvers in sepsis patients with severe refractory hypoxemia due to ARDS (grade 2C).

Рефрактерная гипоксемия

-PaO_2< 70 мм рт.ст. при FiO_2 = 0,8-1,0
- PEEP> 10 см вод.ст.
- длительность более 12-24 часов

Что же мы имеем?

TABLE 19-2 Summary of Clinical Trials Using Alveolar Recruitment Maneuvers in Acute Respiratory Distress Syndrome

Study	No. of Subjects (Intervention/No Intervention)	Study Design*	Intervention(s)	Control	Outcomes	Comments
Novak, 1987[36]	16 (16/0)	NR, C	RM using CPAP 40 cm H_2O for 15-30 sec and bag-sighs	Crossover design	No change in PaO_2 or C_s at 5 min in either group	AHRF patients (before AECC ARDS definition)
Amato, 1995[41]	53 (29/24)	R	RM using CPAP 35-40 cm H_2O for 40 sec with LPV (low VT, high PEEP)	12 mL/kg VT, low PEEP, no RM	↓Mortality (38% vs. 71%) ↑Wean from ventilator (66% vs. 29%)	Improved outcomes due to LVP; benefit of RM unknown
Pelosi, 1999[37]	10 (10/0)	NR	3 Sighs/min for 1 hr using Pplat = 45 cm H_2O	None	Improved PaO_2 and EELV; effect lost at 1 hr	More effective in ARDSexp; LPV used
Lapinsky, 1999[25]	14 (14/0)	NR	RM using CPAP 30-45 cm H_2O for 20 sec	None	70% had better PaO_2 at 4 hr; no adverse events	Early AHRF; LPV not used
Foti, 2000[21]	15 (15/0)	R, C	3 Groups: VC low-PEEP vs. VC high-PEEP vs. VC low-PEEP with RM (PEEP ≤ 20 cm H_2O every 30 sec)	Triple crossover design	Group with RM had improved PaO_2, shunt fraction, C_s vs. VC low-PEEP but worse PaO_2 and shunt fraction vs. VC high-	PEEP-responsive ARDS only; mixed ARDSp/exp; variable ARDS duration

					PEEP	
Crotti, 2001[20]	5 (5/0)	NR	RM using PCV with varying Pplat (30-45 cm H_2O) and PEEP (5-20 cm H_2O) with CT	None	Recruitment is pan-inspiratory; improved gas exchange; no adverse events	Early ARDS; ARDSp/exp; LPV not used; variable ARDS duration
Lim, 2001[27]	20 (20/0)	NR	Two 90-sec sighs with stepwise increase in PEEP and decrease in VT (Pplat ≤ 40 cm H_2O)	None	Improved PaO_2 and C_s at 1 hr; no adverse events	Mixed ARDSp/exp; early ARDS
Richard, 2001[33]	10 (10/0)	NR	RM using CPAP 45 cm H_2O for 15 sec in 6 mL/kg Vt and 10 mL/kg Vt groups	None	Improved short-term PaO_2 and EELV in 6 mL/kg VT group only	Mixed ARDSp/exp; increasing PEEP has same effect as RM
Villagra, 2002[34]	17 (17/0)	NR	RM using 2 min PCV of P_{PK} 50 cm H_2O with PEEP > UIP for 2 min	None	No change in PaO_2 for late or early ARDS; possible overdistention and worsening shunt	LPV used; mixed ARDSp/exp; effect on ARDS duration studied
Patroniti, 2002[30]	13 (13/0)	NR	"Sigh ventilation" for 1 hr (1 sigh/min with 3-5 sec of CPAP ≥ 35 cm H_2O)	None	Improved Pao_2, EELV, and C_s; effect lost after cessation of sighs	Early ARDS; mixed ARDSp/exp; PSV used
Grasso, 2002[23]	22 (22/0)	NR	RM using 40 cm H_2O for 40 sec	None	Improved PaO_2 at 20 min in early	Effect on ARDS duration studied;

					ARDS only; ~25% ↓MAP and CO in late ARDS group	mixed ARDSp/exp; LPV used
Bien, 2002[40]	11 (11/0)	NR	RM using PCV with Pplat = 60 cm H_2O for 30 sec	None	Decrease in MAP and CPP	All patients with cerebral injury
Pelosi, 2003[31]	10 (10/0)	NR	3 Sighs/min for 1 hr using Pplat = 45 cm H_2O in prone/supine	None	Increase in PaO_2, EELV, and C_s better in prone, but effect gone at 1 hr	LPV used; early ARDS
Lim, 2003[26]	47 (47/0)	NR	RM as above (Lim, 2001); 3 groups: RM followed by ↑PEEP vs. RM followed by no change in PEEP vs. ↑PEEP alone	None	Improved PaO_2 in all (best in ARDSexp); effect lost immediately unless ↑PEEP after RM; ARM+ ↑PEEP better than ↑PEEP alone	LVP used; early ARDS
Tugrul, 2003[38]	24 (24/0)	NR	RM using CPAP 45 cm H_2O for 30 sec with ↑PEEP post-RM	None	Improved PaO_2 6 hr post-RM (ARDSexp > ARDSp); improved C_s in ARDSexp	LPV used; no adverse events
ARDSNet, 2003[2]	72 (72/0)	R, C, P, MC	RM using CPAP 35-40 cm H_2O for 5-10 sec every 48 hr (on days	Crossover design with sham RM;	Improved PaO_2 at 10 min (transient), but no	LPV with high PEEP used; protocol for

			1/3 or 2/4)		change in FIO_2/PEEP; no difference by ARDS phenotype; transient ↓BP with RM	changes in FIo_2/PEEP after RM
Oczenski, 2004[29]	30 (15/15)	R	Single RM using CPAP 50 cm H_2O for 30 sec with LPV	LPV without RM	Improved PaO_2 and shunt fraction at 3 min, effect lost at 30 min; no adverse events	Early ARDSexp; PEEP trial before RM
Povoa, 2004[32]	8 (8/0)	NR	RM using PCV with stepwise increase in Pplat/PEEP (max of 60/45) over 30 min	None	Improved PaO_2 and C_s at 30 min	Early ARDS; LPV with high PEEP used; mixed ARDSp/exp
Borges, 2006[39]	26 (26/0)	NR	RM using PCV with stepwise increase in Pplat/PEEP to 60/45 followed by PEEP decremental trial	None	24/26 were recruitable; Improved PaO_2 at 6 hr; transient hypotension and hypercarbia	Early ARDS; mixed ARDSp/exp; LPV with low PEEP pre-RM
Constantin, 2008[19]	19 (19/0)	R, C	2 RM groups: CPAP 40 cm H_2O for 40 sec vs. 15 min sigh (VCV with PEEP 10 cm H_2O above LIP)	Crossover design	Both RM improved PaO_2 (better with sigh); only sigh increased EELV	LPV used; CPAP RM stopped in 2 patients due to hypotension
LOVS, 2008[15]	983 (475/508)	R, MC	LOV: PCV with goal	ARDSNet	LOV with less	Protocolized

			VT 6 mL/kg, Pplat ≤ 40 cm H_2O, high PEEP, RM using CPAP 40 cm H_2O for 40 sec	LPV with no RM	refractory hypoxemia (5% vs. 10%), but no difference in mortality or barotrauma	ventilation strategy

AECC, American-European Consensus Conference; AHRF, acute hypoxemic respiratory failure; $ARDS_{EXP}$, extrapulmonary ARDS; $ARDS_P$, pulmonary ARDS; CO, cardiac output; CPAP, continuous positive airway pressure; CPP, cerebral perfusion pressure; C_s, static respiratory system compliance; CT, computed tomography; EELV, end-expiratory lung volume; LIP, lower inflection point on pressure-volume curve; LOV, "lung open" ventilation strategy; LPV, lung protective ventilation; MAP, mean arterial pressure; PaO_2, partial pressure of arterial oxygen; PCV, pressure-control ventilation; PEEP, positive end-expiratory pressure; P_{PK}, peak pressure; Pplat, plateau pressure; PSV, pressure-support ventilation; RM, recruitment maneuver; VC, volume control; VT, tidal volume; UIP, upper inflection point on pressure-volume curve

Intensive Care Med
DOI 10.1007/s00134-015-4025-5

UNDERSTANDING THE DISEASE

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Understanding recruitment maneuvers

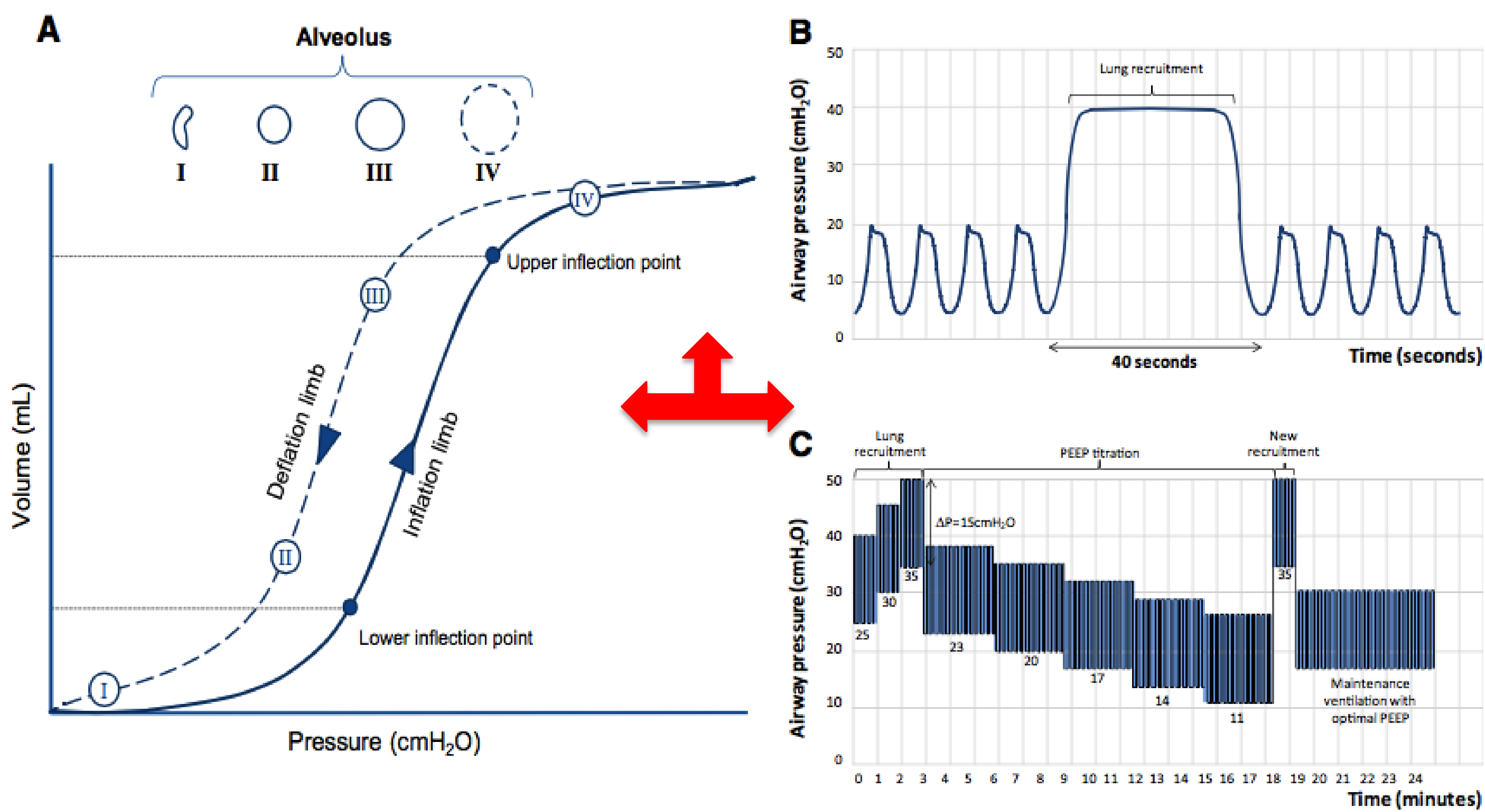

Fig. 1 Pressure–volume curve (**a**). During inflation (*full line*) transpulmonary pressure overcomes the critical opening pressure (upper inflection point). After recruitment maneuver, during deflation (*dotted line*), lung volume is greater at a certain pressure level, and alveoli remain opened as long as positive end-expiratory pressure (PEEP) is kept above a critical pressure level (lower inflection point). Pressure–time (seconds) curve (**b**) showing a sustained inflation recruitment maneuver using continuous positive airway pressure (CPAP) of 40 cmH_2O for 40 s. Pressure–time (minutes) curve showing a stepwise recruitment maneuver (**c**) using both inspiratory pressure and PEEP increases, keeping driving pressure fixed at 15 cmH_2O, achieving peak pressure after recruitment of 50 cmH_2O and PEEP of 35 cmH_2O. After recruitment, figure shows a decremental PEEP titration and a new recruitment maneuver performed after an optimal PEEP is identified (i.e., the PEEP associated with best compliance of respiratory system or best oxygenation). After the new recruitment, PEEP is set 2 cmH_2O above the optimal level

Варианты рекрутмент маневра (1)

- Раскрытие высоким PIP («классический» вариант, Lachmann B., 1992) – технология немного дальше
- Увеличение PIP с 30 до 60 см вод.ст. на 30 сек
- Увеличение PIP до 60 см вод.ст. на 10-30 дыханий при PCV и титрование PEEP с высоких значений (с LIP)
- PC – PIP=40 см вод.ст, PEEP = 20 см вод.ст. в течение 30 сек, повтор 3 раза
- Протокол ИВЛ с малыми Vt
- Ручное использование LIP и UIP

Варианты рекрутмент маневра (2)

- P-V curve (P-V tool)
- Применение PEEP = 40 (30-35) см вод.ст на 40 сек, FiO2 – 1,0
- Применение PEEP = 40 см вод.ст. на 10 (20) сек (кардиохирургия, «малое» влияние на гемодинамику)
- «Медленный» рекрутмент – VC, Vt=**10** (8) мл/кг, PEEP = 15 см вод.ст., пауза в конце вдоха на 7 секунд 2 раза/мин в течение 15 минут
- Неинвазивный рекрутмент – n-CPAP = 10 см вод.ст., n-CPAP + Sigh

Варианты рекрутмент маневра (3)

- Перемежающийся PEEP, например 35 см вод.ст. 1 раз в час на 3-5 секунд.
- Автоматический «вздох» – Sigh, 3 вздоха в час с PIP = 45 см вод.ст.

TRIALS

STUDY PROTOCOL Open Access

Rationale, study design, and analysis plan of the Alveolar Recruitment for ARDS Trial (ART): Study protocol for a randomized controlled trial

The ART Investigators

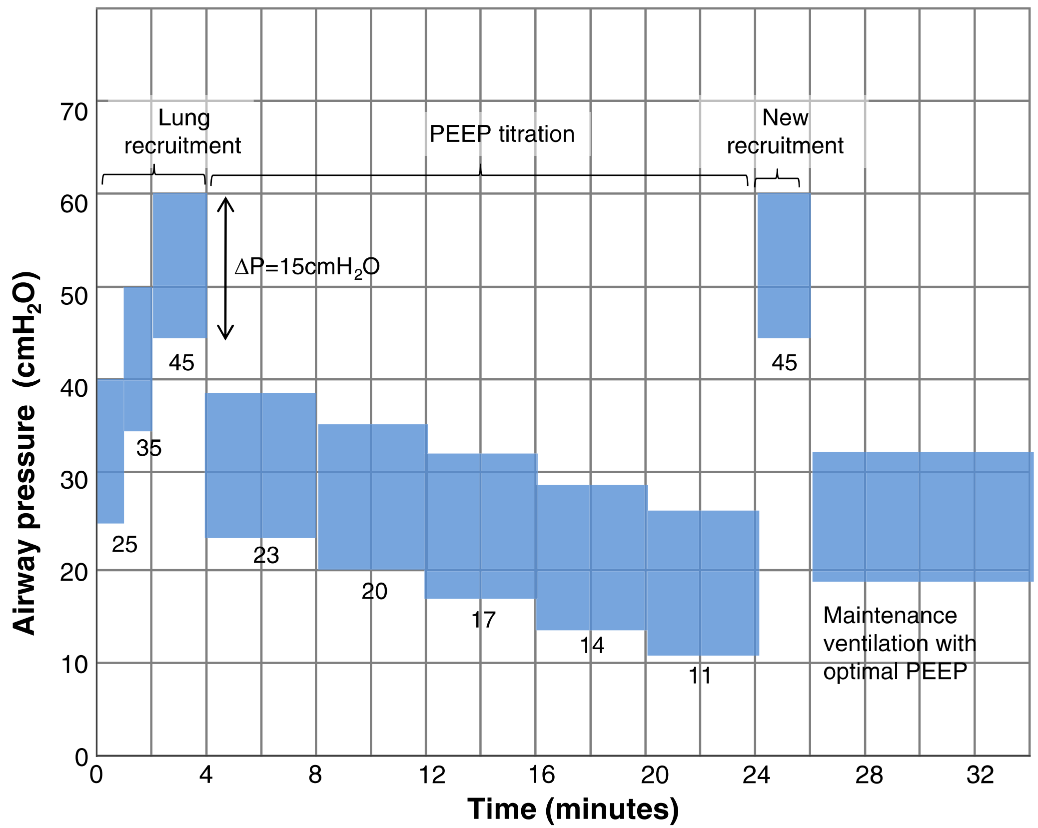

Figure 1 ART strategy: maximum alveolar recruitment maneuver associated with PEEP titration.

Intensive Care Med (2011) 37:1588–1594
DOI 10.1007/s00134-011-2323-0

ORIGINAL

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Optimal duration of a sustained inflation recruitment maneuver in ARDS patients

Table 1 Baseline characteristics of the study population and outcomes for the 50 patients included

Parameter	Value
Age (years)	62 ± 20
Sex (male/female)	32/18
SAPS II	52 ± 15
Body mass index (kg/m^2)	22 ± 8
Duration mechanical ventilation before inclusion (days)	0.3 ± 0.9
Tidal volume/PBW (mL/kg)	8.0 ± 1.2
Plateau pressure (cmH$_2$O)	24 ± 4
C_{STAT} (mL/cmH$_2$O)	30 ± 9
FiO$_2$ (%)	71 ± 20
pH	7.25 ± 0.10
PaO$_2$/FiO$_2$ (mmHg)	129 ± 37
PaCO$_2$ (mmHg)	45 ± 10
ARDS causes (*n*/%)	
Inhalation	21/42
Pneumonia	13/26
Septic shock	7/14
Near-drowning	6/12
Pulmonary contusion	2/4
Acute pancreatitis	1/2
Total duration of mechanical ventilation (days)	10 ± 10
Total duration of ICU stay (days)	11 ± 10
Mortality in ICU (*n*/%)	23/46

Values are mean ± SD
PBW, predicted body weight; C_{STAT}, static compliance

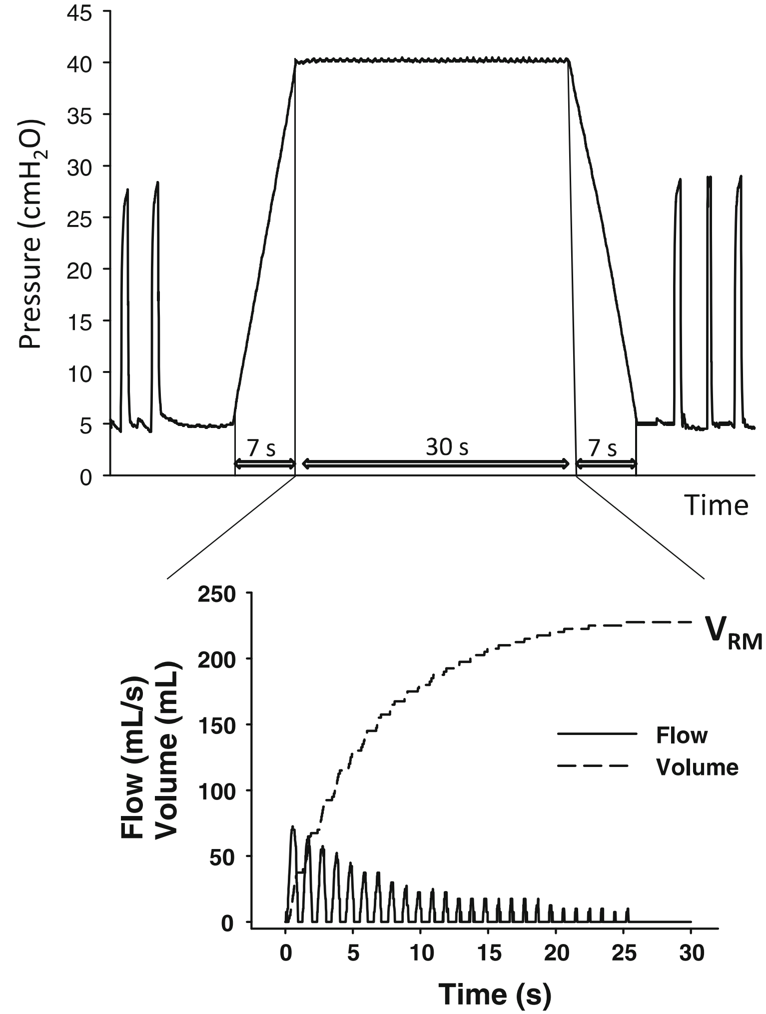

Fig. 1 Representation of the experimental protocol: airway pressure was increased from either 5 or 10 cmH$_2$O to 40 cmH$_2$O. RM used the sustained inflation method at 40 cmH$_2$O for 30 s (*upper panel*). If recruitment occurs, the total volume of the lung increases. As a consequence, airway pressure decreases. To maintain the airway pressure at 40 cmH$_2$O, the ventilator inflates the lung with spikes of flow (*solid line in lower panel*). Integration of the spikes of flow measured at the airway is used to calculate the volume increase during the RM (V_{RM}) (*dashed line in lower panel*) as an assessment of the volume recruited during the RM

ARDSnet

NIH NHLBI ARDS Clinical Network
Mechanical Ventilation Protocol Summary

INCLUSION CRITERIA: Acute onset of

1. $PaO_2/FiO_2 \leq 300$ (corrected for altitude)
2. Bilateral (patchy, diffuse, or homogeneous) infiltrates consistent with pulmonary edema
3. No clinical evidence of left atrial hypertension

PART I: VENTILATOR SETUP AND ADJUSTMENT

1. Calculate predicted body weight (PBW)
   Males = 50 + 2.3 [height (inches) - 60]
   Females = 45.5 + 2.3 [height (inches) -60]
2. Select any ventilator mode
3. Set ventilator settings to achieve initial V_T = 8 ml/kg PBW
4. Reduce V_T by 1 ml/kg at intervals ≤ 2 hours until V_T = 6ml/kg PBW.
5. Set initial rate to approximate baseline minute ventilation (not > 35 bpm).
6. Adjust V_T and RR to achieve pH and plateau pressure goals below.

OXYGENATION GOAL: PaO_2 55-80 mmHg or SpO_2 88-95%
Use a minimum PEEP of 5 cm H_2O. Consider use of incremental FiO_2/PEEP combinations such as shown below (not required) to achieve goal.

Lower PEEP/higher FiO2

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	14	14	14	16	18	18-24

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	18	20	22	22	22	24

PLATEAU PRESSURE GOAL: ≤ 30 cm H_2O
Check Pplat (0.5 second inspiratory pause), at least q 4h and after each change in PEEP or V_T.
If Pplat > 30 cm H_2O: decrease V_T by 1ml/kg steps (minimum = 4 ml/kg).
If Pplat < 25 cm H_2O and V_T< 6 ml/kg, increase V_T by 1 ml/kg until Pplat > 25 cm H_2O or V_T = 6 ml/kg.
If Pplat < 30 and breath stacking or dys-synchrony occurs: may increase V_T in 1ml/kg increments to 7 or 8 ml/kg if Pplat remains ≤ 30 cm H_2O.

http://www.ardsnet.org

APPENDIX D

Summary of Ventilator Procedures in the Higher PEEP Groups of the ALVEOLI Trial

Procedure	Value
Ventilator mode	Volume assist/control
Tidal volume goal	6 mL/kg of predicted body weight
Plateau pressure goal	≤ 30 cm H_2O
Ventilator rate and pH goal	6–35, adjusted to achieve arterial pH ≥ 7.30 if possible
Inspiration expiration time	1:1–1:3
Oxygenation goal	
Pa_{O_2}	55–80 mm Hg
Sp_{O_2}	88%–95%
Weaning	Weaning attempted by means of pressure support when level of arterial oxygenation acceptable with PEEP < 8 cm H_2O and F_{IO_2} < 0.40
Allowable combinations of PEEP and F_{IO_2}[a]	
Higher PEEP group (after protocol changed to use higher levels of PEEP)	

F_{IO_2}	0.3	0.3	0.4	0.4	0.5	0.5	0.5–0.8	0.8	0.9	1
PEEP	12	14	14	16	16	18	20	22	22	22–24

Note: Complete ventilator procedures and eligibility criteria can be found at www.ardsnet.org.

Sp_{O_2} = oxyhemoglobin saturation as measured by pulse oximetry, F_{IO_2} = fraction of inspired oxygen, PEEP = positive end-expiratory pressure.

[a]In both study groups (lower and higher PEEP), additional increases in PEEP to 34 cm H_2O were allowed but not required after F_{IO_2} had been increased to 1.0, according to the protocol.

Adapted from Brower RG, Lanken PN, MacIntyre N, et al: Higher vs. lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome.
N Engl J Med. 2004; 351(4):327–336.

Intensive Care Med (2005) 31:1370–1378
DOI 10.1007/s00134-005-2746-6

ORIGINAL

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Inspiratory vs. expiratory pressure-volume curves to set end-expiratory pressure in acute lung injury

Abstract *Objective:* To study the effects of two levels of positive end-expiratory pressure (PEEP), 2 cmH_2O above the lower inflection point of the inspiratory limb and equal to the point of maximum curvature on the expiratory limb of the pressure-volume curve, in gas exchange, respiratory mechanics, and lung aeration. *Design and setting:* Prospective clinical study in the intensive care unit and computed tomography ward of a university hospital. *Patients:* Eight patients with early acute lung injury. *Interventions:* Both limbs of the static pressure-volume curve were traced and inflection points calculated using a sigmoid model. During ventilation with a tidal volume of 6 ml/kg we sequentially applied a PEEP 2 cmH_2O above the inspiratory lower inflection point (15.5±3.1 cmH_2O) and a PEEP equal to the expiratory point of maximum curvature (23.5±4.1 cmH_2O). *Measurements and results:* Arterial blood gases, respiratory system compliance and resistance and changes in lung aeration (measured on three computed tomography slices during end-expiratory and end-inspiratory pauses) were measured at each PEEP level. PEEP according to the expiratory point of maximum curvature was related to an improvement in oxygenation, increase in normally aerated, decrease in nonaerated lung volumes, and greater alveolar stability. There was also an increase in $PaCO_2$, airway pressures, and hyperaerated lung volume. *Conclusions:* High PEEP levels according to the point of maximum curvature of the deflation limb of the pressure-volume curve have both benefits and drawbacks.

Keywords Acute lung injury · Positive end-expiratory pressure · Pressure-volume curves · Computed tomography · Mechanical ventilation

Fig. 1 Representative pressure-volume curve in a patient. Data pairs of pressure and volume from the inspiratory and expiratory limbs (filled and open points, respectively) were used to calculate a model of the curve (continuous line) and the inflection points (LIP and PMC, arrows)

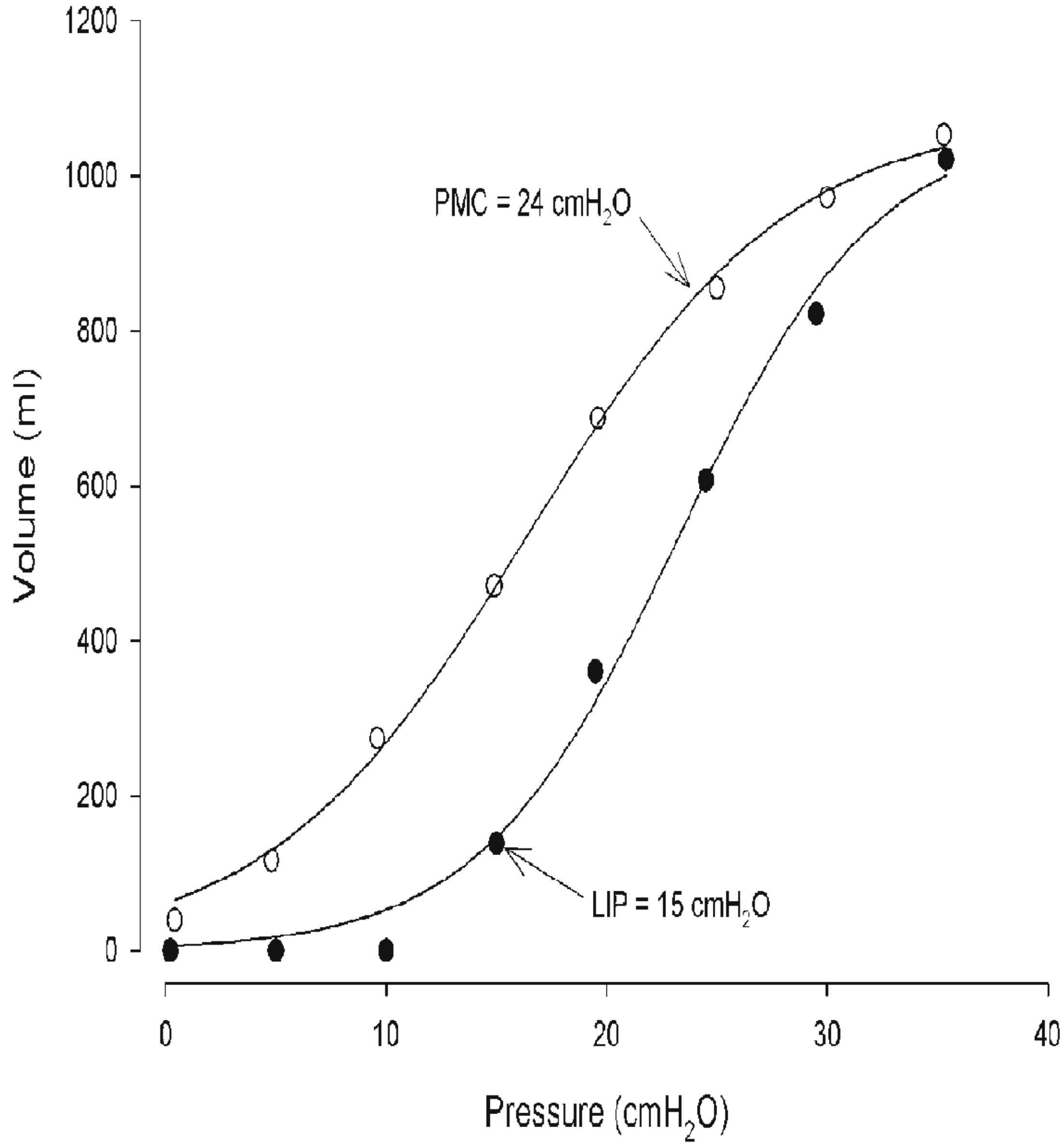


Table 1 Patients characteristics: diagnosis, age and sex (*A-II* Acute Physiology and Chronic Health Evaluation II score, *LIS* lung injury score)

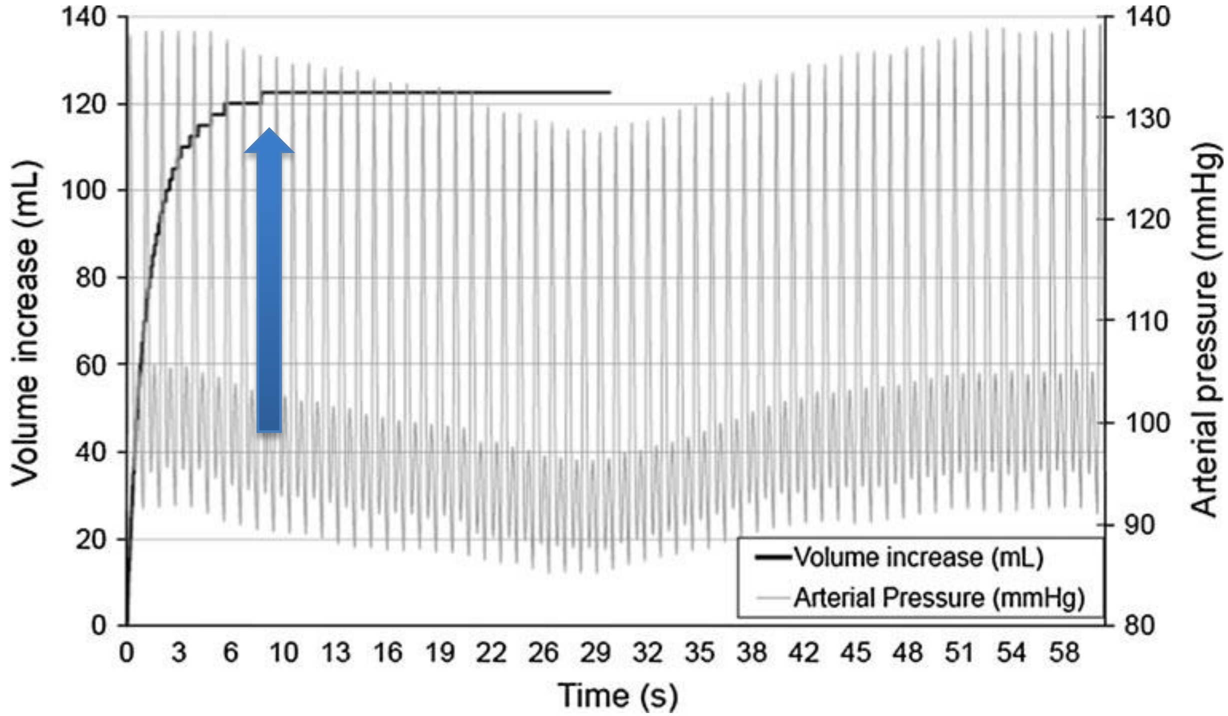
No.	Diagnosis; cause of lung injury	Age (years)	Sex	A-II	PaO_2/FIO_2	LIS	Height (cm)	Outcome
1	Pancreatitis	81	F	19	125	3.25	150	Death
2	Leukemia; alveolar hemorrhage	49	M	29	160	3.75	175	Survival
3	Urinary sepsis; septic shock	63	M	30	123	3	170	Death
4	Cardiac arrest; gastric aspiration	74	M	19	171	2.75	177	Death
5	Leukemia; pneumonia	56	M	25	192	3	175	Death
6	Hemorrhagic shock	47	F	25	97	3.5	155	Survival
7	Incarcerated hernia; gastric aspiration	80	M	27	201	2.75	174	Death
8	Septic shock of unknown origin	64	F	25	162	3.25	148	Death
Mean	–	64.3	–	24.9	154	3.2	165.5	–
SD	–	13.2	–	4.1	36	0.3	12.3	–

Table 2 Airway pressures, compliance and resistances during ventilation above the lower inflection point (LIP) and the point of maximum curvature (PMC) on the inflation and deflation limbs of the pressure-volume curve respectively

	LIP +2 cmH_2O	PMC	*p*
Auto-PEEP (cmH_2O)	0.7±0.6	0.5±0.4	0.12
Peak pressure (cmH_2O)	38.4±3.7	48.7±5.4	<0.01
Plateau pressure (cmH_2O)	27.3±3.7	37.2±5.3	<0.01
PEEP (cmH_2O)	15.5±3.1	23.5±4.1	<0.05
Driving pressure (cmH_2O)	11.8±2.4	13.7±3.9	0.08
Compliance (ml/cmH_2O)	35.7±13.9	29.2±8.3	0.095
Total resistance ($cmH_2O\ s^{-1}\ l^{-1}$)	12.3±1.2	12.0±1.3	0.13
Intrinsic resistance ($cmH_2O\ s^{-1}\ l^{-1}$)	3.7±1.1	4.6±1.4	0.13
Additional resistance ($cmH_2O\ s^{-1}\ /l^{-1}$)	8.6±0.7	7.3±0.8	0.15

Выводы: Применение PEEP по точке RMC, полученной с помощью кривой давление-объем имеет как преимущества, так и недостатки.

Fig. 5 Representative case of a patient showing the volume increase (V_{RM}) and the invasive arterial pressure during and after the RM



In conclusion, this study provides direct evidence that most of the recruitment occurs early during a sustained inflation RM in ARDS patients which confirms the experimental animal study data [14]. However, hemodynamic impairment is a progressive phenomenon throughout the sustained inflation RM. These results could influence the design of optimal sustained inflation RM in ARDS patients. A 10-s sustained inflation RM may be recommended to achieve a plateau in the volume recruited and to prevent hemodynamic compromise.

Intensive Care Med (2005) 31:1189–1194
DOI 10.1007/s00134-005-2732-z

ORIGINAL

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Lung recruitment maneuver depresses central hemodynamics in patients following cardiac surgery

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Abstract *Objective:* To assess the impact of the lung recruitment maneuver on circulation following cardiac surgery. *Design and setting:* Prospective randomized cross-over study at the Departments of Anesthesia and Thoracic Surgery, Copenhagen University Hospital. *Patients:* Ten adult undergoing coronary artery bypass surgery. *Interventions:* Patients were randomized to two durations of lung recruitment maneuvers (40 cmH_2O airway pressure for 10 s and 20 s or vice versa after 5 min) administered immediately after surgery. *Measurements and results:* Transesophageal echocardiography (left ventricular short axis view), pulse contour cardiac output, and arterial blood pressure were monitored continuously. Systemic and pulmonary arterial blood gases were sampled before and after each lung recruitment maneuver to calculate the intrapulmonary shunt. Left ventricular end-diastolic areas decreased significantly during both the 10-s and the 20-s lung recruitment maneuvers. Cardiac output was 5.6±0.8 l/min at baseline, decreasing by 3.0±1.1 l/min and 3.6±1.2 l/min during lung recruitment maneuvers of 10 and 20 s, respectively. Shunt decreased from 20±5% to 15±6% after the first lung recruitment maneuver and from 15±6% to 12±5% after the second. *Conclusions:* Lung recruitment maneuvers markedly reduced cardiac output and left ventricular end-diastolic areas in hemodynamically stable patients following cardiac surgery.

Keywords Lung recruitment maneuver · Cardiac output · Cardiac surgery · Pulse contour cardiac output · Transesophageal echocardiography · Anesthesia

Table 1 Patient demographics and values relevant to anesthesia and surgery: median values (*parentheses* range) (n=10)

Age (years)	67 (54–79)
Height (cm)	178 (168–190)
Weight (kg)	82 (71–118)
Body mass index	26 (20–36)
Cardiopulmonary bypass time (min)	82 (44–97)
Aortic clamping time (min)	47 (27–70)
Left ventricular ejection fraction (%)	50[a] (45–70)

[a] Missing LVEF value presented as "normal" by investigator

Table 3 The impact of 10-s and 20-s lung recruitment maneuvers on hemodynamics: median values (*parentheses* range) (*HR* heart rate, *MAP* mean arterial pressure, *CVP* central venous pressure, *MPAP* mean pulmonary artery pressure, *Difference* before vs. end of value)

	Before	End	Difference	*p*
10-s				
HR (bmp)	68 (57 to 80)	58 (59 to 89)	−4 (−24 to 9)	<0.07
MAP (mmHg)	72 (59 to 110)	60[a] (47 to 93)	−17 (−41 to 6)	<0.01
CVP (mmHg)	12 (7 to 30)	15 (7 to 32)	3 (−1 to 14)	<0.02
MPAP (mmHg)	19[a] (13 to 26)	28[a] (22 to 50)	11 (6 to 24)	<0.004
20-s				
HR (bpm)	72 (59 to 89)	57[a] (30 to 84)	−15 (-29 to 0)	<0.02
MAP (mmHg)	79 (56 to 114)	37[a] (29 to 59)	−33 (-14 to 79)	<0.004
CVP (mmHg)	10 (4 to 31)	20[a] (13 to 33)	8 (2 to 20)	<0.005
MPAP (mmHg)	17[a] (12 to 33)	25[a] (20 to 34)	9 (0 to 21)	<0.02

[a] Missing value due to recording error by the monitor

Intensive Care Med (2005) 31:1706–1714
DOI 10.1007/s00134-005-2799-6

EXPERIMENTAL

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Slow moderate pressure recruitment maneuver minimizes negative circulatory and lung mechanic side effects: evaluation of recruitment maneuvers using electric impedance tomography

Abstract *Objective:* To evaluate the efficacy of different lung recruitment maneuvers using electric impedance tomography. *Design and setting:* Experimental study in animal model of acute lung injury in an animal research laboratory. *Subjects:* Fourteen pigs with saline lavage induced lung injury. *Interventions:* Lung volume, regional ventilation distribution, gas exchange, and hemodynamics were monitored during three different recruitment procedures: (a) vital capacity maneuver to an inspiratory pressure of 40 cmH_2O (ViCM), (b) pressure-controlled recruitment maneuver with peak pressure 40 and PEEP 20 cmH_2O, both maneuvers repeated three times for 30 s (PCRM), and (c) a slow recruitment with PEEP elevation to 15 cmH_2O with end inspiratory pauses for 7 s twice per minute over 15 min (SLRM). *Measurements and results:* Improvement in lung volume, compliance, and gas exchange were similar in all three procedures 15 min after recruitment. Ventilation in dorsal regions of the lungs increased by 60% as a result of increased regional compliance. During PCRM compliance decreased by 50% in the ventral region. Cardiac output decreased by 63±4% during ViCM, 44±2% during PCRM, and 21±3% during SLRM. *Conclusions:* In a lavage model of acute lung injury alveolar recruitment can be achieved with a slow lower pressure recruitment maneuver with less circulatory depression and negative lung mechanic side effects than with higher pressure recruitment maneuvers. With electric impedance tomography it was possible to monitor lung volume changes continuously.

Keywords Lung recruitment · End-expiratory lung volume · Acute lung injury · Bronchoalveolar lavage · Electric impedance tomography

Intensive Care Med (2011) 37:1095–1102
DOI 10.1007/s00134-011-2239-8

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Influence of lung collapse distribution on the physiologic response to recruitment maneuvers during noninvasive continuous positive airway pressure

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Abstract *Purpose:* Noninvasive continuous positive airway pressure (n-CPAP) has been proposed for the treatment of hypoxemic acute respiratory failure (h-ARF). Recruitment maneuvers were shown to improve oxygenation, i.e., the ratio of arterial oxygen tension to inspiratory oxygen fraction (PaO_2/FiO_2), during either invasive mechanical ventilation, and n-CPAP, with a response depending on the distribution of lung collapse. We hypothesized that, during n-CPAP, early h-ARF patients with bilateral (B_L) distribution of lung involvement would benefit from recruitment maneuvers more than those with unilateral (U_L) involvement. *Methods:* To perform a recruitment maneuver, once a minute we increased the pressure applied to the airway from 10 cmH_2O to 25 cmH_2O for 8 s (SIGH). We enrolled 24 patients with h-ARF (12 B_L and 12 U_L) who underwent four consecutive trials: (1) 30 min breathing through a Venturi mask (V_{MASK}), (2) 1 h n-CPAP (n-$CPAP_1$), (3) 1 h n-CPAP plus SIGH (n-$CPAP_{SIGH}$), and (4) 1 h n-CPAP (n-$CPAP_2$). *Results:* Compared to V_{MASK}, n-CPAP at 10 cmH_2O delivered via a helmet, increased PaO_2/FiO_2 and decreased dyspnea in both B_L and U_L; furthermore, it reduced the respiratory rate and brought $PaCO_2$ up to normal in B_L only. Compared to n-CPAP, n-$CPAP_{SIGH}$ significantly improved PaO_2/FiO_2 in B_L (225 ± 88 vs. 308 ± 105, respectively), whereas it produced no further improvement in PaO_2/FiO_2 in U_L (232 ± 72 vs. 231 ± 77, respectively). SIGH did not affect hemodynamics in both groups. *Conclusions:* Compared to n-CPAP, n-$CPAP_{SIGH}$ further improved arterial oxygenation in B_L patients, whereas it produced no additional benefit in those with U_L.

Keywords Noninvasive CPAP · Recruitment maneuvers

ment. *Methods:* To perform a recruitment maneuver, once a minute we increased the pressure applied to the airway from 10 cmH_2O to 25 cmH_2O for 8 s (SIGH). We enrolled 24 patients with h-ARF

Intensive Care Med (2011) 37:1595–1604
DOI 10.1007/s00134-011-2333-y

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PEEP-induced changes in lung volume in acute respiratory distress syndrome. Two methods to estimate alveolar recruitment

Table 1 Arterial blood gas values and ventilation during the minimum distension (low PEEP) and high recruitment (high PEEP) periods

	Low PEEP	High PEEP	*p* value
$PEEP_{tot}$ (cmH_2O)	5 [5]	15 [13–16]	<0.0001
Pplat (cmH_2O)	19 [16–23]	29 [29–31]	<0.0001
C_{stat} (mL/cmH_2O)	31.4 [24.1–38.6]	28.0 [23.4–31.9]	0.02
C_{lin} (mL/cmH_2O)	32.7 [25.0–40.8]	29.0 [24.5–32.9]	<0.0001
pH	7.38 [7.33–7.44]	7.37 [7.31–7.41]	0.03
PaO_2/FiO_2	142 [106–176]	173 [126–215]	<0.0001
SaO_2 (%)	95 [93–97]	98 [95–99]	<0.0001
$PaCO_2$ (mmHg)	39.5 [36.0–45.7]	41.0 [35.2–45.7]	0.8
EELV (mL)	888 [658–1,078]	1,487 [987–1,803]	<0.0001
PEEP volume (mL)	170 [112–245]	662 [463–961]	<0.0001
Strain	0.27 [0.19–0.34]	0.70 [0.53–0.83]	<0.0001

All data are median [interquartile range]

Low PEEP Lowest PEEP set to achieve $SaO_2 \geq 88\%$, *high PEEP* PEEP set to obtain a plateau pressure of 28–32 cmH_2O, C_{stat} static compliance calculated as VT/(Pplat–PEEP), C_{lin} linear compliance measured on the linear part of the pressure/volume curve

The *p* values refer to the comparison of low to high PEEP

Table 4 Pulmonary volumes and strain in the low and high recruiter subgroups defined based on the median recruited volume (Rec_{mes}) measured on pressure-volume curves

	All patients $n = 30$	Low recruiters $n = 15$	High recruiters $n = 15$	p value
Volumes				
PEEP volume, low PEEP (mL)	170 [112–245]	157 [126–239]	184 [99–248]	0.8
PEEP volume, high PEEP (mL)	662 [463–961]	471 [356–644]	923 [726–1094]	0.001
ΔPEEP volume (mL)	501 [314–705]	322 [224–458]	713 [609–944]	0.0002
EELV, low PEEP (mL)	888 [658–1,078]	816 [629–1,023]	931 [776–1,067]	0.4
EELV, high PEEP (mL)	1,487 [987–1,803]	1,080 [885–1,504]	1,645 [1,487–2,000]	0.03
ΔEELV (mL)	444 [276–689]	373 [192–402]	658 [534–804]	0.0007
FRC[a] (mL)	685 [526–900]	582 [482–885]	743 [546–966]	0.5
ΔEELV/FRC (%)	73 [39–106]	55 [23–70]	110 [76–135]	0.001
FRC_{th}[b] (mL)	2,266 [1,896–2,540]	2,211 [1,841–2,814]	2,266 [2,089–2,512]	0.8
Minimum predicted increase in lung volume[c] (mL)	249 [182–393]	180 [145–237]	382 [289–432]	0.001
Rec_{mes} (mL)	272 [191–355]	187 [135–214]	355 [319–494]	<0.0001
Rec_{estim} (mL)	187 [67–297]	74 [22–215]	278 [145–475]	0.007
Strain, low PEEP[d]	0.27 [0.19–0.34]	0.29 [0.21–0.34]	0.25 [0.13–0.37]	0.47
Strain, high PEEP[e]	0.70 [0.53–0.83]	0.60 [0.48–0.77]	0.79 [0.66–0.91]	0.04
ΔStrain[f]	0.43 [0.31–0.55]	0.32 [0.28–0.40]	0.55 [0.46–0.60]	0.002

Values are median [interquartile range] unless otherwise indicated. Median recruitment was 272 mL [187–355]

The p values refer to the comparison of low and high recruiters

EELV End expiratory lung volume measured using the nitrogen washout/washin technique, *ΔEELV* difference between EELV values at high and low PEEP, *PEEP volume* volume trapped by PEEP, *ΔPEEP volume* difference between PEEP volumes at high and low PEEP, *ΔPEEP* calculated as the difference between high PEEP and low PEEP, *FRC* functional residual capacity

[a] FRC was calculated as the mean of estimated FRC at low and high PEEP, with estimated $FRC_{low\ PEEP} = (EELV_{low\ PEEP} - \text{PEEP volume}_{low\ PEEP})$ (Fig. 1)

[b] Theoretical FRC (FRC_{th}) was calculated using the formula proposed by Ibáñez and Raurish [16]

[c] Minimum predicted increase in lung volume was calculated as $C_{stat} \times \Delta PEEP$, where C_{stat} is static compliance [tidal volume/(Pplat measured at low PEEP − low PEEP)] and ΔPEEP is the difference between high PEEP and low PEEP

[d] Strain, low PEEP = (EELV at low PEEP − FRC at low PEEP)/FRC at low PEEP

[e] Strain, high PEEP = (EELV at high PEEP − FRC at high PEEP)/(FRC at high PEEP + Rec_{mes})

[f] ΔStrain = strain, high PEEP − strain, low PEEP

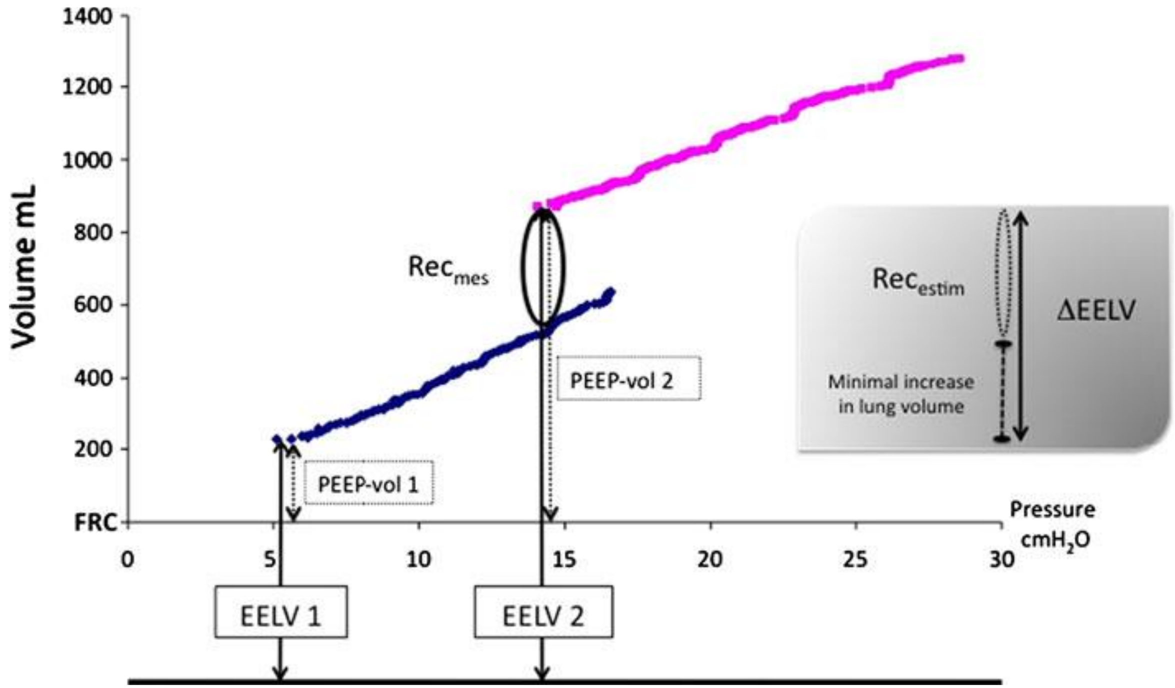
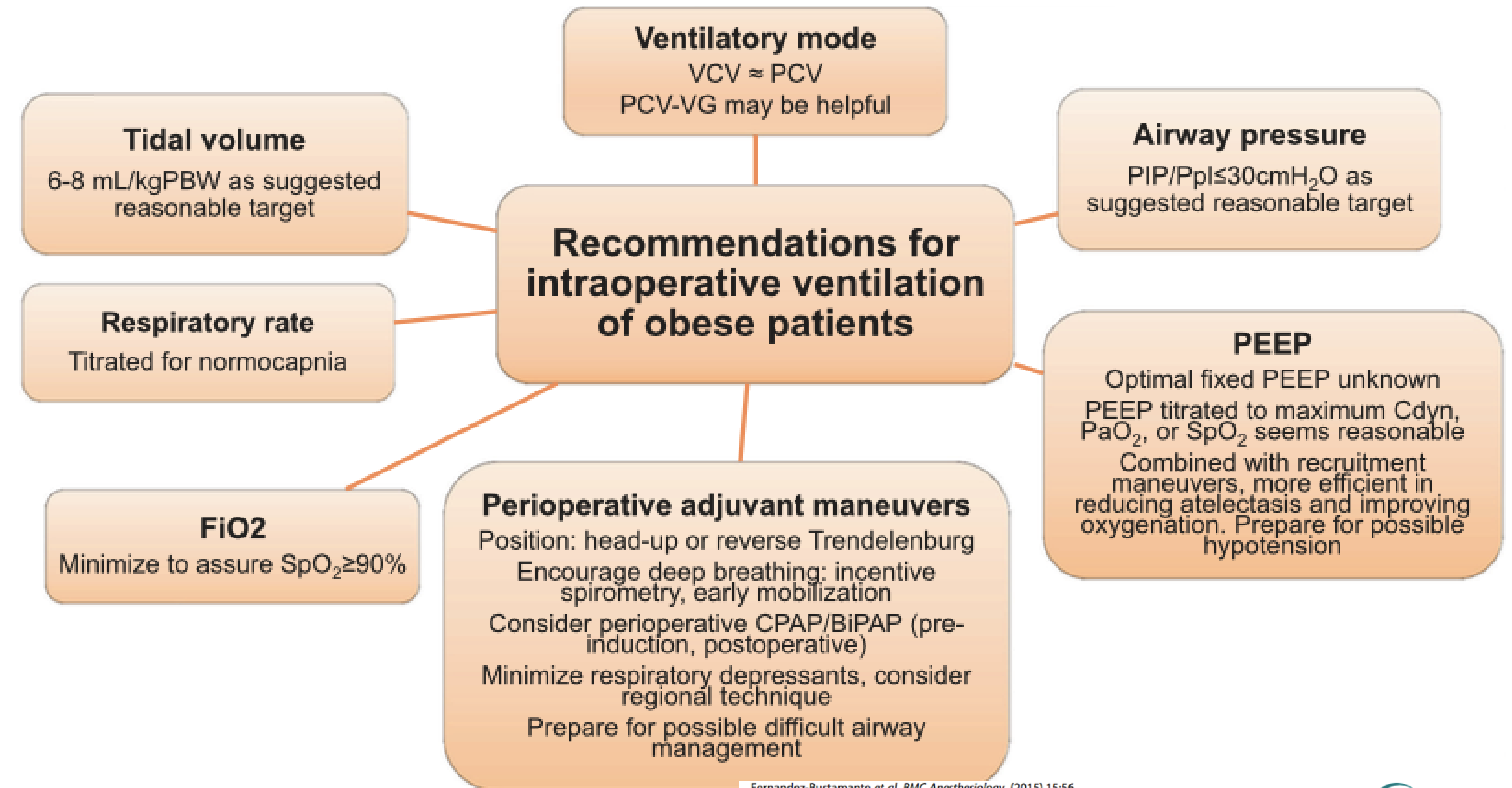


Fig. 1 Example of pressure-volume curves in a single patient, at both positive end-expiratory pressure (PEEP) levels studied (here low PEEP = 5 cmH_2O and high PEEP = 14 cmH_2O), repositioned on the same volume axis. The *solid line* indicates end-expiratory lung volume (EELV) measured using nitrogen washout/washin technique. EELV represents the aerated volume in the lungs at the end of expiration. *Dashed line* indicates the PEEP volume, i.e., expired volume from PEEP to elastic pressure measured using a prolonged exhalation to zero end expiratory pressure. FRC is estimated as the mean of ($EELV_{low\ PEEP}$ − PEEP $volume_{low\ PEEP}$) and ($EELV_{high\ PEEP}$ − PEEP $volume_{high\ PEEP}$). Rec_{mes} is the recruitment induced by PEEP change measured on the graph. Rec_{estim} is the recruitment calculated using ΔEELV − the minimum predicted increase in lung volume, which is the product of compliance and ΔPEEP. *Grey inset* is a schematic representation of Rec_{estim}

($p = 0.002$). *Conclusion:* PEEP-induced recruitment and strain can be assessed at the bedside using EELV measurement. We describe two bedside methods for predicting low or high alveolar recruitment during ARDS.

Немного особенностей))



(Cdyn=Dynamic compliance; BiPAP=Bilevel positive airway p
fraction of oxygen; PaO_2=Arterial oxygen partial pressure; PB
VG=Pressure controlled ventilation volume guaranteed; PEEI
Ppl=Plateau airway pressure; SpO_2=Peripheral saturation of

Figure 1 Practical recommendations for intraoperative ventilation of o

Fernandez-Bustamante *et al. BMC Anesthesiology* (2015) 15:56
DOI 10.1186/s12871-015-0032-x

BMC Anesthesiology

REVIEW Open Access

Perioperative lung protective ventilation in obese patients

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Маневр «открытия» легких

- Wolf S. et al. **Open lung ventilation in neurosurgery: an update on brain tissue oxygenation** // Acta Neurochir Suppl. 2005; 95:103-5

- Применение рекрутмент - маневра при острой внутричерепной патологии и ОРДС у нейрохирургических больных возможно (13 пациентов с субарахноидальным кровоизлиянием и ЧМТ) .
- Оценка PbrO2.
- **Маневр при FiO_2 =1,0 по технологии: PEEP = 30-40 см вод.ст. в течение 40 секунд.**
- В среднем через 17 минут после первого маневра набора, PbrO2 = 35,6$\pm$16,6 мм рт.ст. (улучшение).
- В течение 24 часов FiO_2 может быть уменьшена с 0,85$\pm$0,17 до 0,55$\pm$0,12 при среднем PbrO2 (24,6 мм рт.ст. до рекрутмента).

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Спасибо за внимание!!!

Вопросы?