



Step-by-step guide

How to perform lung recruitment gently and efficiently

Based on clinical protocols by Dr. Carlos Ferrando.

Important notes

- Suggestions are related to adult patients with healthy lungs undergoing surgery. The settings should only be regarded as examples of a typical recruitment maneuver.
- The responsible physician shall always base pre-selected values on the clinical judgment of the individual patient's physiology.
- Obese patients, or patients undergoing laparoscopy, may require higher pressures to achieve an open lung condition. They may also need higher PEEP values to keep the lungs open.
- Recruitment maneuvers in pediatric patients should be carefully applied. Lower opening pressures are required and PEEP values need to be carefully selected.
- To improve achievement, adequate sedation and relaxation are needed.
- Hemodynamics before and during the maneuver should be continuously checked. A transitory drop in cardiac output/arterial pressure may appear.

Abbreviations

RM	Recruitment Maneuver
OLA	Open Lung Approach
EIP	End Inspiratory Pressure
PPC	Postoperative Pulmonary Complications

Explanations

Driving pressure = $EIP - PEEP$
in VC $EIP = \text{Plateau pressure}$

A lung protective approach includes reducing the driving pressure, which has shown to be positively associated with survival.¹

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Keeping patients' lungs healthy

Atelectasis affects over 90%² of patients during general anesthesia, regardless of gender, age, health condition or length of surgery, showing the importance of a lung protective strategy.

Atelectasis persists even after they have left the operating room.³

An open lung approach (OLA), recruiting the lungs and keeping them open, aims to restore the functional lung volume.⁴

A recent study demonstrates that the risk for PPC:s among patients is high when performing recruitment maneuvers by bag squeezing techniques.⁵

Efficient ventilator-controlled recruitment maneuvers (RM) don't have to be complicated or time-consuming.

In this step-by-step guide Dr. Carlos Ferrando will demonstrate how he uses the automatic stepwise RM function in the Flow-i Anesthesia Machine.



Open-lung ventilation

– a physiological approach

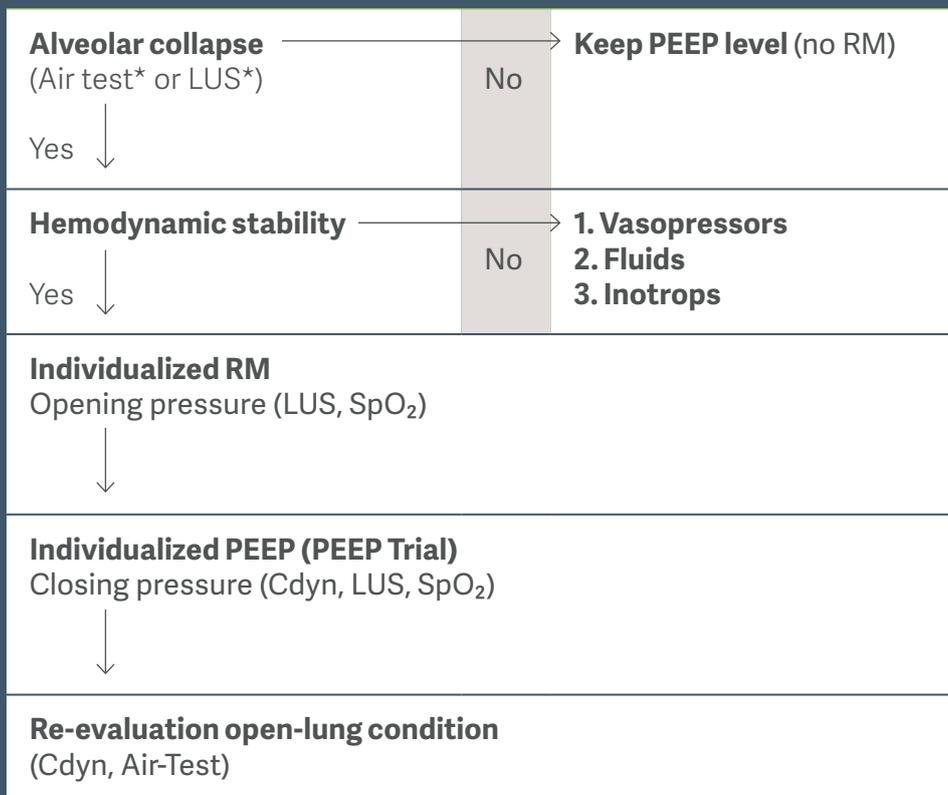
The open lung approach (OLA) to ventilation involves increasing the level of Positive End Expiratory Pressure (PEEP), in combination with protective lung ventilation, to minimize post-operative complications (PPC) related to anesthesia.

The model below describes how to perform RM:s with an open-lung approach (iPROVE algorithm).

The first steps include assessing the need for RM as well as asserting that the patient is sufficiently hemodynamic stable.

The following steps describe how to find the opening pressure, closing pressure and how to evaluate the efficiency of the RM. For detailed information, see case 1 and 2 in this guide.

The iProve algorithm



- * **Air test** : 5 min of breathing with 0.21 F_iO₂ (Air)
- SpO₂ ≤ 96% Positive (shunt induced by lung collapse)
- SpO₂ ≥ 97% Negative

** **LUS**: Lung Ultra Sonic Examination

Case 1

Auto RM

April 11 2018, University Clinico Hospital, Valencia, Spain

Carlos Ferrando MD, PhD, DESA

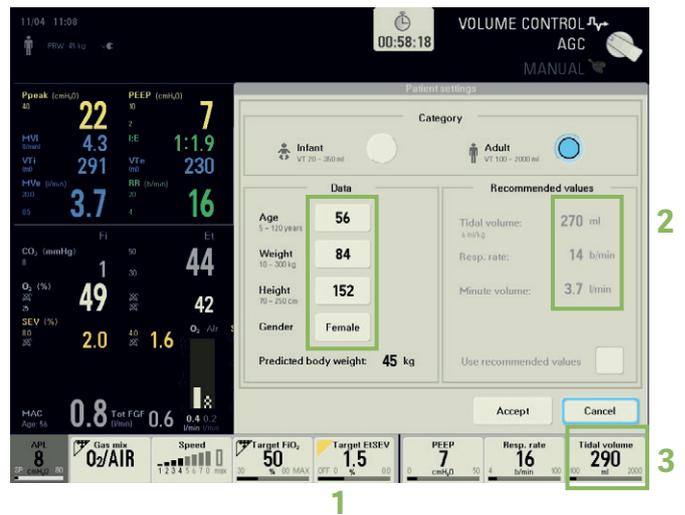
Patient data

Gender	Woman
Age	56
RBW	84 kg
PBW	45 kg
Height	152 cm
BMI	36 kg/m ²
Medical history	None
Surgery	Bariatric
SpO₂ (0.21 F_iO₂) pre-operatively	98%
SpO₂ (0.21 F_iO₂) 15 min after induction	93% - Air-test positive
SpO₂ (0.21 F_iO₂) post-operatively	98%

In this case VC is used after RM and for PEEP titration, but PC or PRVC are also possible to use.

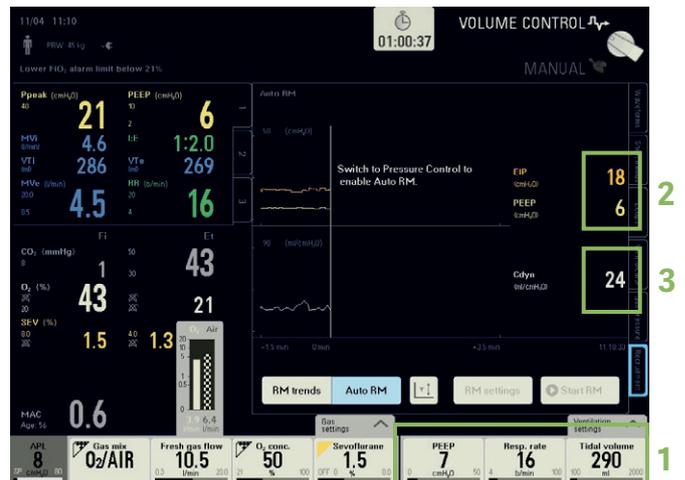
1. Patient settings

- Enter the patient data. (1)
- Start by using the recommended values for the calculated PBW (6 ml/kg). (2)
- Do adjustments to reach desired baseline ventilation. (3)



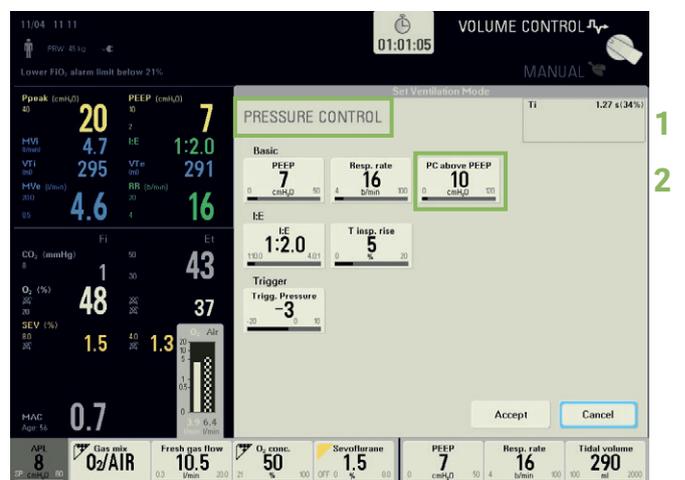
2. Baseline ventilation identified

- TV=290 ml, RR=16, PEEP=7. (1)
- Driving pressure 18 - 6=12 cmH₂O. (2)
- Prerecruitment Cdyn=24. (3)



3. Set ventilation mode

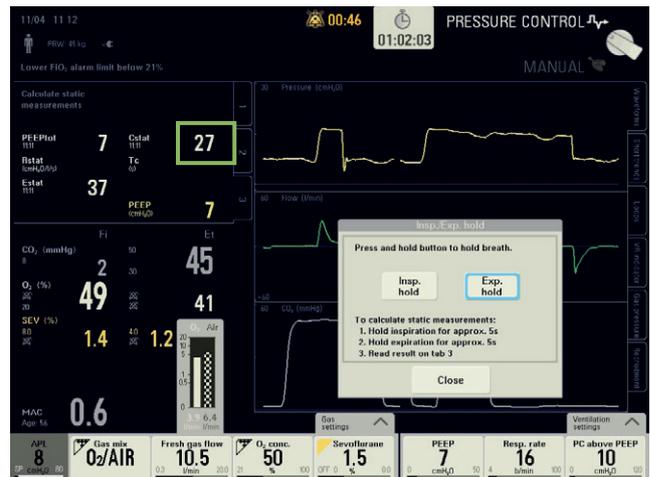
- To enable Auto RM switch to PC. (1)
- Reduce the driving pressure to 10 cmH₂O to avoid a high TV. (2)



4. Insp./Exp. hold

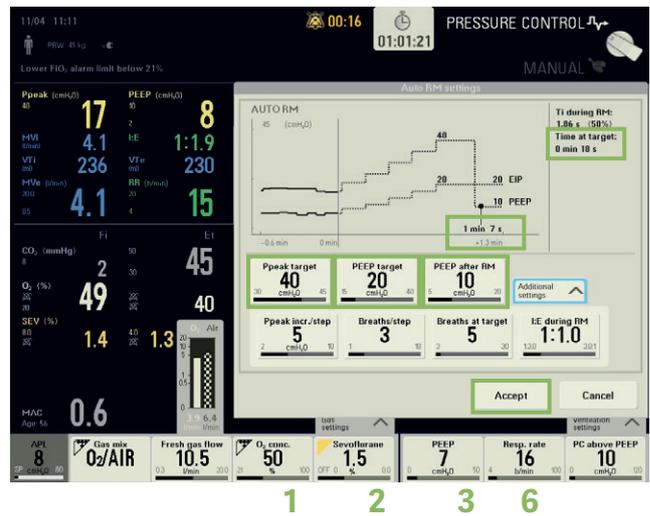
- Measure the baseline static compliance as a reference. In this case Cstat = 27. (1)

1



5. Auto RM settings

- Open up the tab for the recruitment maneuver.
- Individualize the settings.
- In this case:
 - Stepwise increase in EIP up to 40 cmH₂O (1)
 - Stepwise increase in PEEP up to 20 cmH₂O (2)
 - PEEP after RM = 10 cmH₂O (3)
 - Time at Target: 18 sec (4)
 - Duration: 1 min and 7 sec (5)
- Accept. (6)



4

5

1

2

3

6

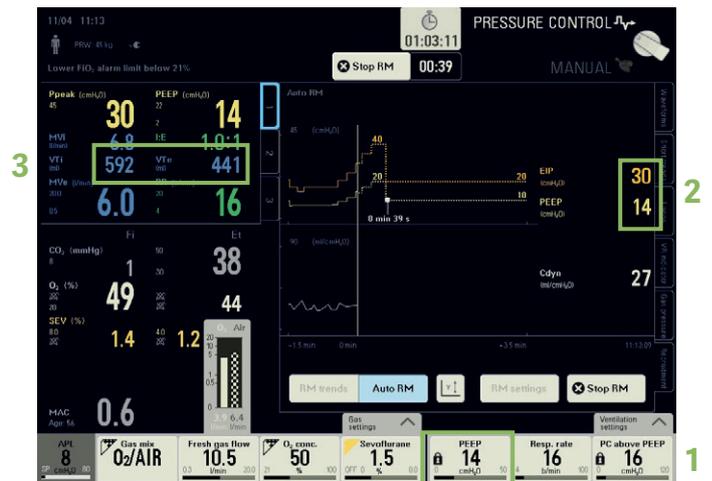
6. Start Auto RM

- Press Start RM.



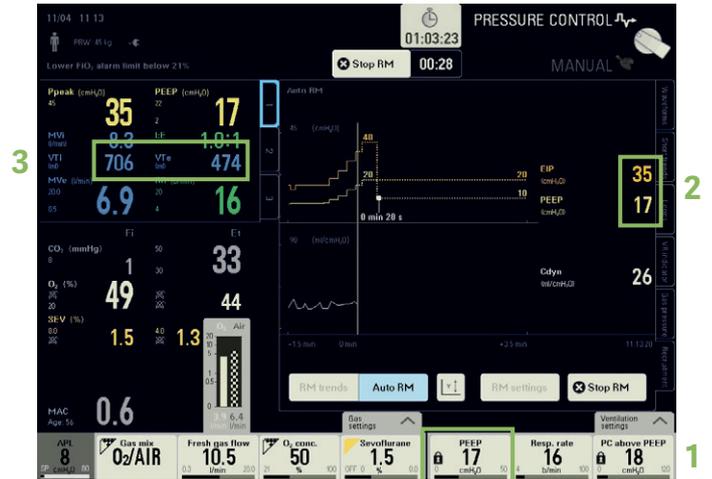
7. Ongoing recruitment maneuver

- PEEP 14 cmH₂O. (1)
- Driving pressure 16 cmH₂O. (2)
- Increase in TV. (3)



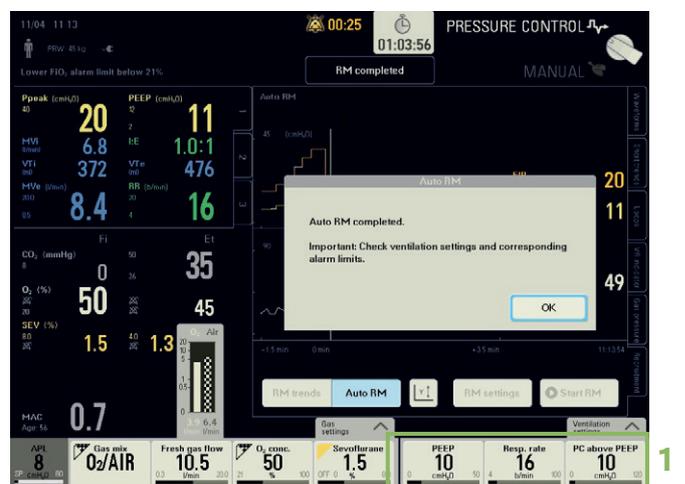
8. Ongoing recruitment maneuver

- PEEP 17 cmH₂O. (1)
- Driving pressure 18 cmH₂O. (2)
- Increase in TV. (3)



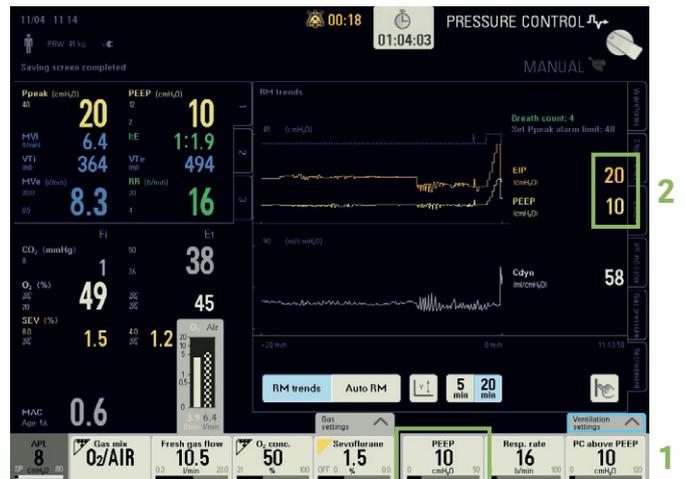
9. Recruitment maneuver completed

- It is important to change to predefined parameters after the RM to avoid insufficient ventilation. (1)



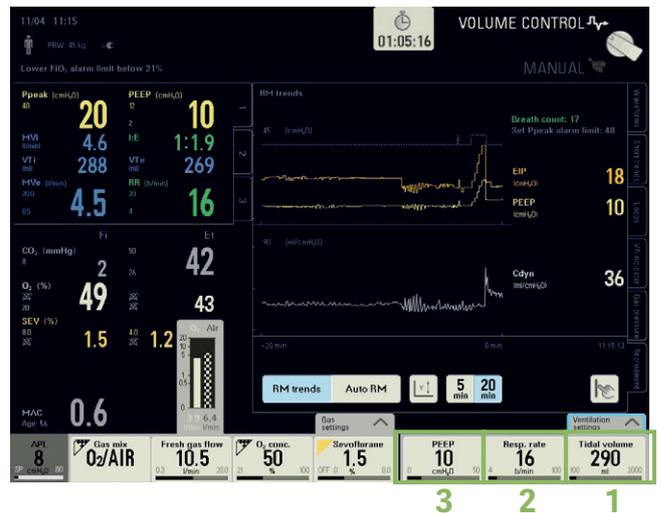
10. Pressure Control: pre-adjusted anesthesia machine settings

- PEEP 10 cmH₂O. (1)
- Driving pressure 10 cmH₂O (Observe that the TV is much higher after RM). (2)



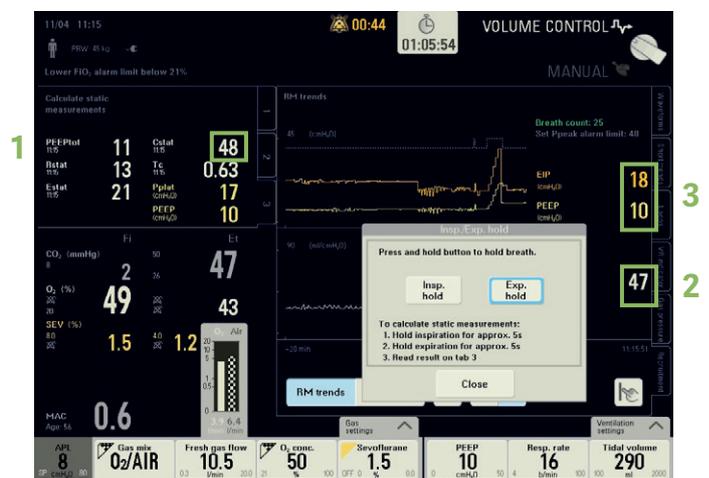
11. Change back to Volume Control

- Same settings as before the maneuver to establish protective ventilation.
 - TV = 290 ml (1)
 - RR = 16 (2)
 - PEEP = 10 (to keep the lung open after the recruitment maneuver) (3)



12. Final outcome!

- Static compliance = 48 cmH₂O. (1)
- Cdyn = 47 cmH₂O. (2)
- Driving pressure reduced from 12 to 8 cmH₂O (18-10). (3)



Case 2

Auto RM including PEEP titration

March 23 2018, University Clinic Hospital, Valencia, Spain

Carlos Ferrando MD, PhD, DESA

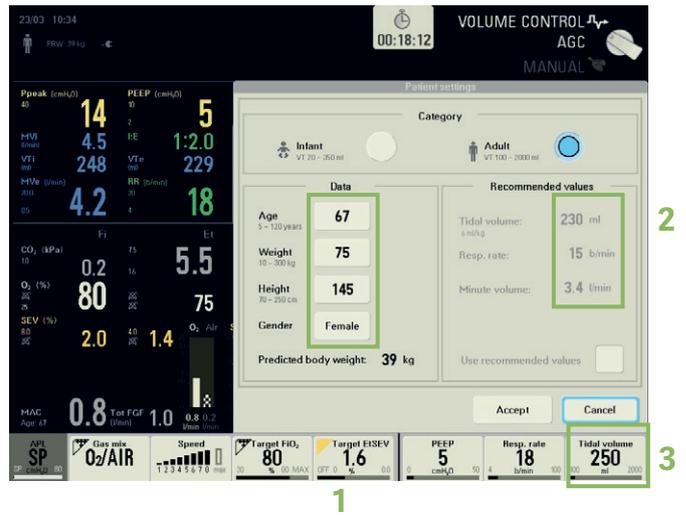
Patient data

Gender	Woman
Age	67
RBW	75 kg
PBW	36 kg
Height	145 cm
BMI	38 kg/m ²
Medical history	Arterial hypertension, Diabetes, Dyslipidemia.
Surgery	Hepatic metastasectomy
SpO₂ (0.21 F_iO₂) pre-operatively	98%
SpO₂ (0.21 F_iO₂) 15 min after in- duction	92% - Air-test positive
SpO₂ (0.21 F_iO₂) post-operatively	98%

In this case VC is used after RM and for PEEP titration, but PC or PRVC are also possible to use.

1. Patient settings

- Enter the patient data. (1)
- Start by using the recommended values for the calculated PBW (6 ml/kg). (2)
- Do adjustments to reach the desired baseline ventilation. (3)



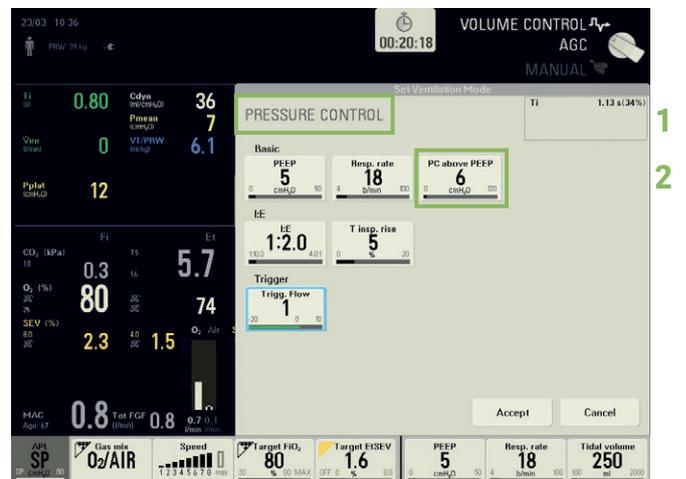
2. Baseline ventilation identified

- TV=250 ml, RR=18, PEEP=5. (1)
- Driving pressure 12-5=7 cmH₂O. (2)
- Prerecruitment Cdyn=36. (3)



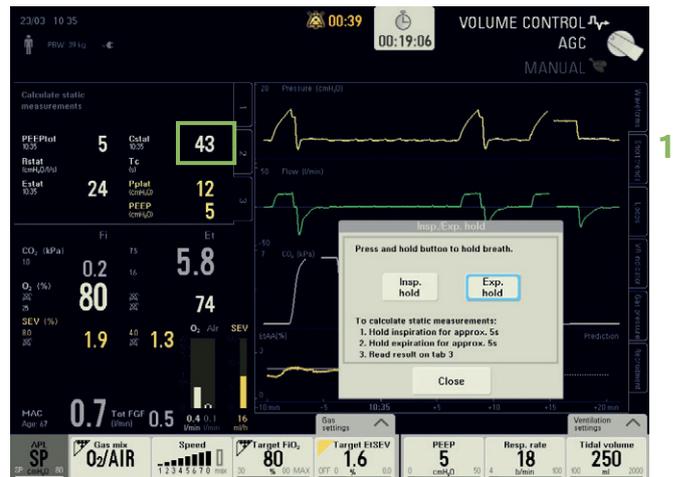
3. Set ventilation mode

- To enable Auto RM switch to PC. (1)
- Reduce the driving pressure to 6 cmH₂O to avoid a high TV. (2)



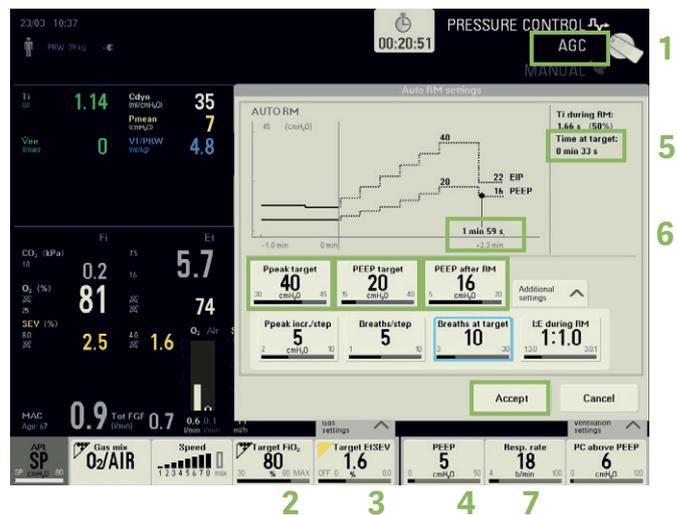
4. Insp./Exp. hold

- Measure a baseline static compliance as a reference. In this case Cstat = 43. (1)



5. Auto RM settings

- AGC is activated throughout the maneuver. (1)
- Stepwise increase in EIP up to 40 cmH₂O. (2)
- Stepwise increase in PEEP up to 20 cmH₂O. (3)
- Selected PEEP after RM = 16 cmH₂O (to enable a PEEP titration). (4)
- Time at Target: 33 sec. (5)
- Duration: 1 min and 59 sec. (6)
- Accept. (7)



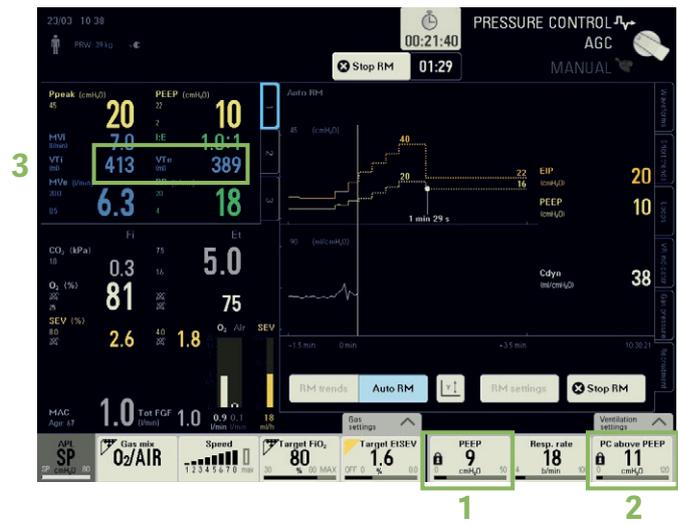
6. Start Auto RM

- Press Start RM.



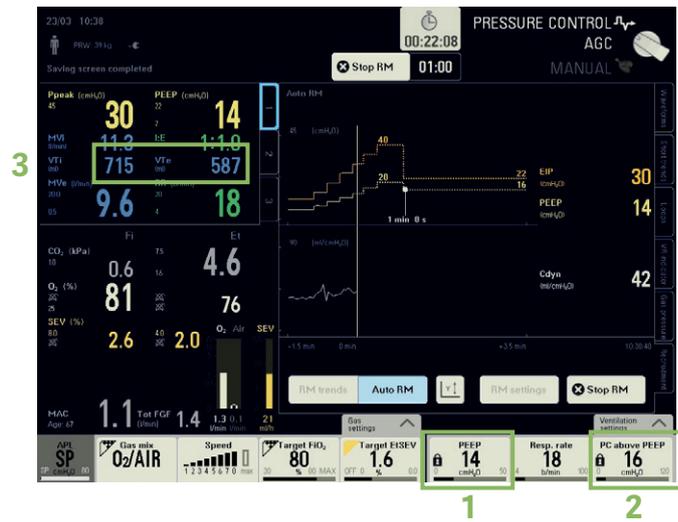
7. Ongoing recruitment maneuver

- PEEP 9 cmH₂O. (1)
- Driving pressure 11 cmH₂O. (2)
- Increase in TV. (3)



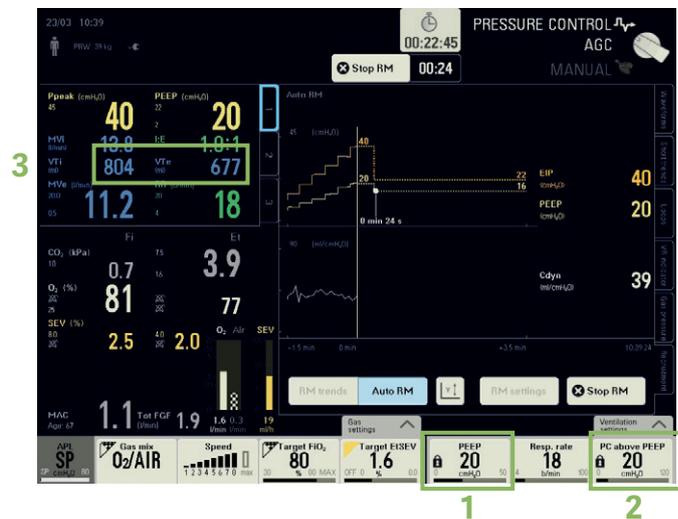
8. Ongoing recruitment maneuver

- PEEP 14 cmH₂O. (1)
- Driving pressure 16 cmH₂O. (2)
- Increase in TV. (3)



9. Ongoing recruitment maneuver

- PEEP 20 cmH₂O. (1)
- Driving pressure 20 cmH₂O. (2)
- Increase in TV. (3)



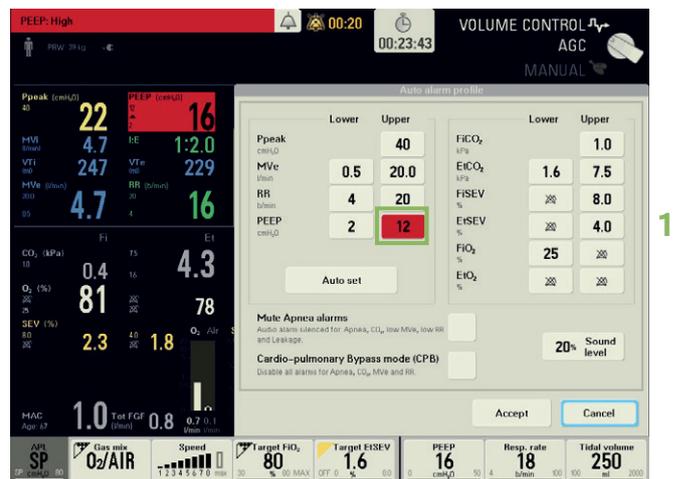
10. Recruitment maneuver completed

- Automatic change to predefined parameters after the RM. (1)



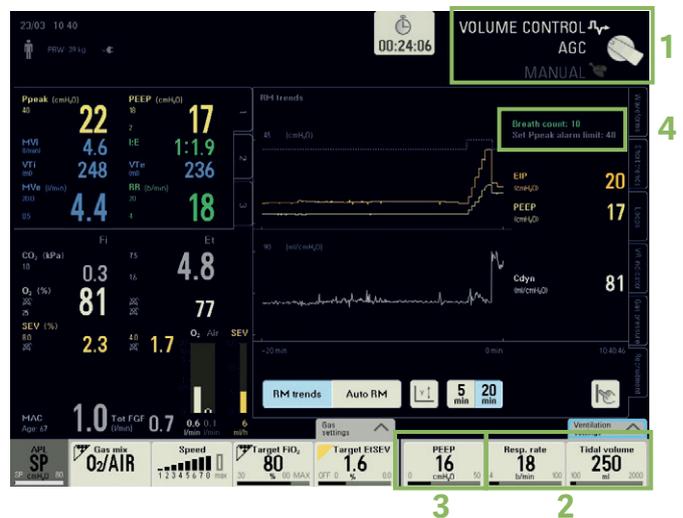
11. PEEP alarm

- The high PEEP alarm is re-activated after the recruitment as a reminder that the PEEP level is high. (1)



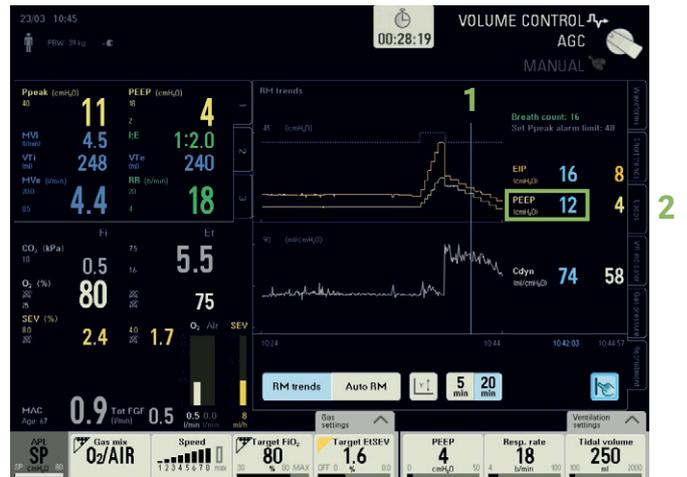
12. PEEP titration

- PEEP titration trial in Volume Control. (1)
 - Adjust the baseline ventilation settings
- TV=250 ml, RR=18. (2)
- Decrease the PEEP step of 2 cmH₂O for approx. 10 breaths each step and search for PEEP for best Cdyn. (3)
- The breath count is displayed in green colour. (4)



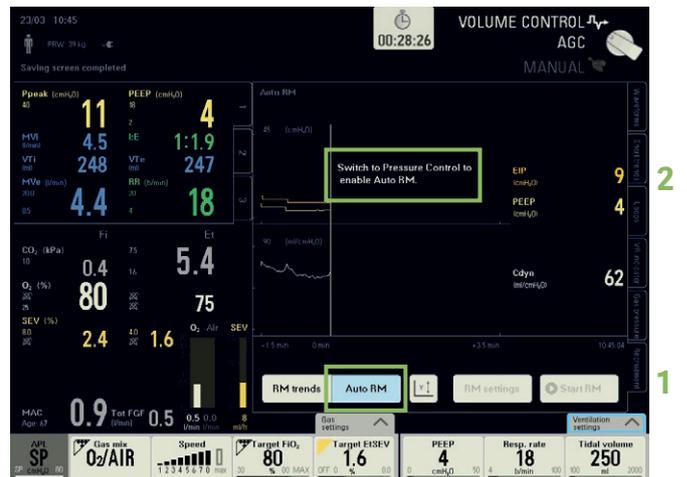
13. PEEP titration

- When there is a clear drop in Cdyn, start searching for the PEEP value with highest Cdyn and lowest driving pressure. (1)
- In this case PEEP 12 cmH₂O. (2)



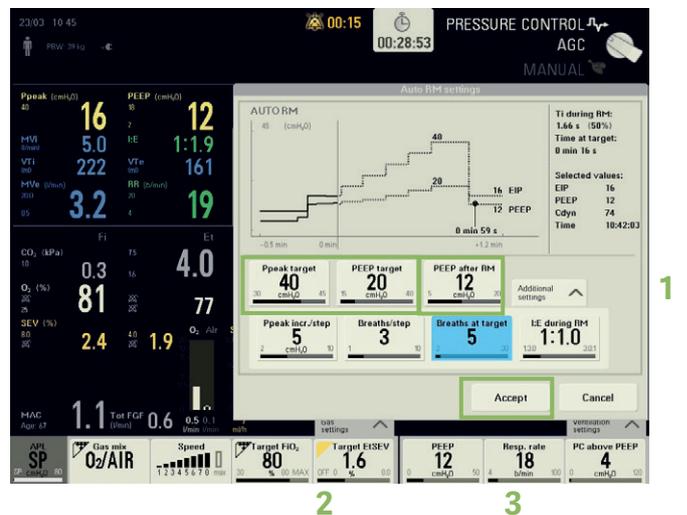
14. Perform a re-recruitment

- Press Auto RM. (1)
- Go back to PC to enable the recruitment maneuver. (2)



15. Re-recruitment settings

- Set the PEEP after RM to 12 cmH₂O = just above closing pressure. (1)
- Keep the other settings from the previous recruitment. (2)
- Accept and start the 2nd recruitment. (3)



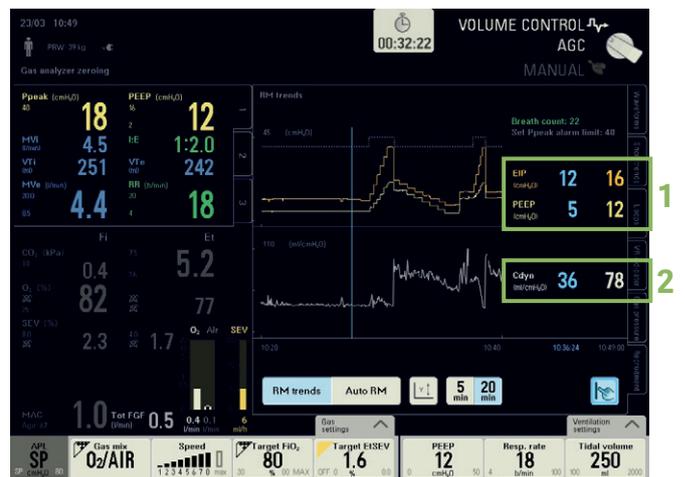
16. Change back to Volume Control

- After completed RM, select Volume Control. (1)
- Same settings as before the maneuver to establish protective ventilation. (2)
 - TV = 250 ml.
 - RR = 18.
 - PEEP = 12 (to keep the lung open after the recruitment maneuver).



17. Final outcome!

- Driving pressure reduced from 7 cmH₂O (12–5) to 4 cmH₂O (16–12). (1)
- Cdyn increased from 36 ml/cmH₂O to 78 ml/cmH₂O. (2)



Appendix: Reference guide for printing

The following three pages serve as a quick reference guide that summarize how to perform efficient and gentle automatic RM:s with the Flow-i Anesthesia Machine according to the two options presented earlier.



TIP

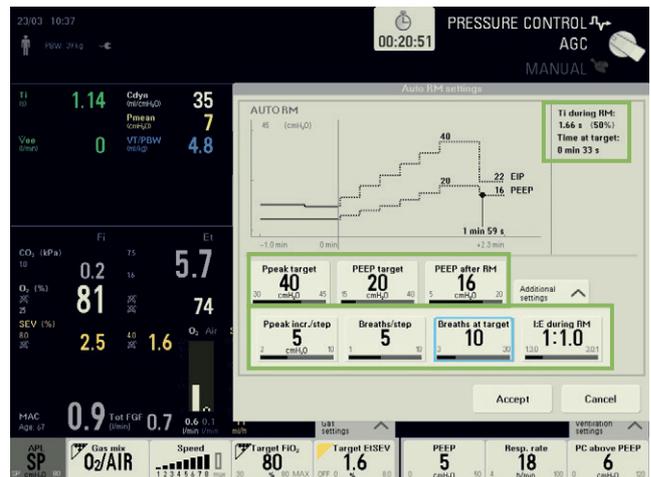
Print the pages, laminate and hang on your Flow-i anesthesia machines. We recommend printing pages 1+2 or 1+3, or 1+2+3.

Step-by-step reference guide for Flow-i

Gentle and efficient lung recruitment

Auto RM settings

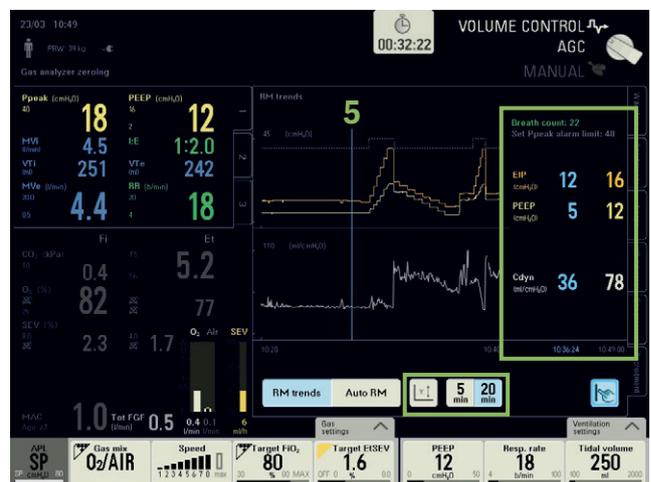
- 1
 - **Time at Target**
 - **Ti during RM** – inspiratory time in sec
- 2
 - **Ppeak Target** – EIP Target
 - **PEEP Target**
 - **PEEP after RM** – set proper level to prevent lung collapse
- 3
 - **Ppeak incr./step** – total increase in pressure each step
 - **Breath/step** – number of breaths each step
 - **Breaths at Target** – number of breaths at target
 - **I:E during RM** – the I:E is changed to a preconfigured value



1
2
3

Trend window

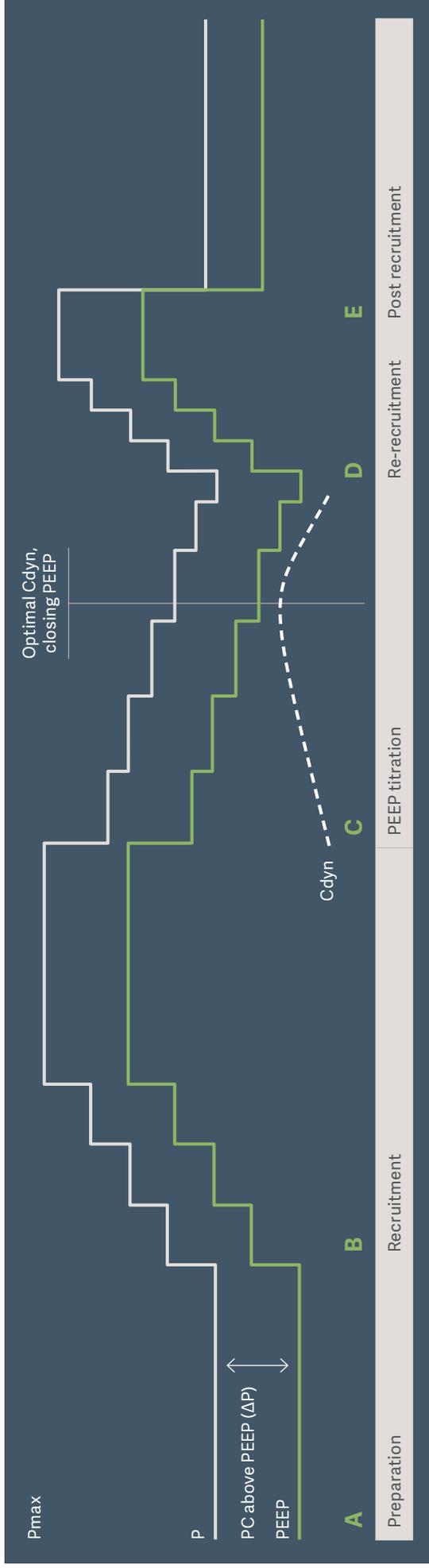
- 4
 - Breath count resets after change in PEEP or PC above PEEP
 - **EIP** – End Inspiratory Pressure
 - **PEEP**
 - **Cdyn** – dynamic compliance
- 5
 - Cursor to be used to find the highest compliance value (vertical blue line)
- 6
 - Scale adjustment (Pressure and Compliance)
 - 5 or 20 min trend view



4
5
6

IMPORTANT NOTES

- Suggestions are related to adult patients with healthy lungs undergoing surgery. The settings should only be regarded as an example of the typical recruitment maneuver.
- The responsible physician shall always base pre-selected values on the clinical judgement of the individual patient's physiology.
- Obese patients or patients undergoing laparoscopy may require higher pressures to achieve an open lung condition. They may also need higher PEEP values to keep the lung open.
- Recruitment maneuvers in pediatric patients should be very carefully applied. Lower opening pressure are required and PEEP values need to be very carefully selected.
- In order to improve achievement, adequate sedation and relaxation is needed.
- Hemodynamics before and during the maneuver should be continuously checked. A transitory drop in cardiac output/arterial pressure may appear.
- Refer to the user manual for operation of the anesthesia machine.



A. Preparation

1. Choose PC mode.
2. Confirm that the PBW is set.
3. Open the recruitment tab
4. Decide the target for:
 - EIP
 - PEEP
 - PEEP after RM*
5. Check additional settings. Stay at EIP target for 30–45 seconds.
6. Confirm settings.

* If PEEP titration is performed, select 16–18 cmH₂O

This document is intended to provide information to an international audience outside of the US.

Refer to the user manual for operation of the anesthesia machine. MX-7275 Rev02 - Protocol contributed by Carlos Ferrando MD, PhD, Surgical intensive care unit, Hospital Clinico Barcelona, Spain.

B. Recruitment

1. Start Auto RM.
2. Observe Cdyn.
3. Observe vital signs.

C. PEEP titration

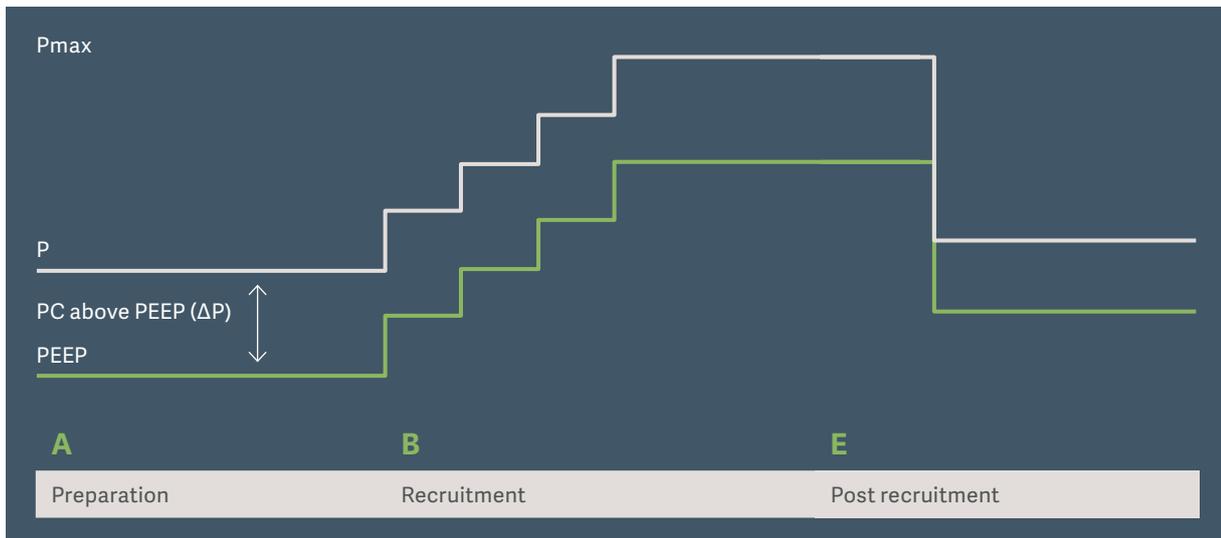
1. Use the RM Trend window.
2. Choose VC or PC.
3. If PC is used, observe the volumes and decrease the PC above PEEP (ΔP) if needed.
4. Start titration by decreasing the PEEP in steps of 2 cmH₂O (e.g 18, 16, 14...)
5. Stay at PEEP decrement for at least 6–8 breaths and check the Cdyn trend curve.
6. Identify the closing PEEP, i.e. the point where the Cdyn has passed its maximum and a decreasing trend has been identified. If VC is used this PEEP-level corresponds to the point where the driving pressure is as lowest.

D. Re-recruitment

1. Redo recruitment as in B.
2. Select open lung PEEP, i.e. 2 cmH₂O above the closing PEEP.
3. Stay at target for 20–30 seconds.

E. Post recruitment

1. Change to mode of choice e.g. PRVC, PC, VC.
2. Lower the PC above PEEP (ΔP) or the tidal volume to achieve the optimal VT/PBW (ml/kg).
3. Readjust the alarm limits for PEEP and Ppeak.



A. Preparation

1. Choose PC mode.
2. Confirm that the PBW is set.
3. Open the recruitment tab
4. Decide the target for:
 - EIP
 - PEEP
 - PEEP after RM
5. Check additional settings.
Stay at EIP target for 30–45 seconds.
6. Confirm settings.

B. Recruitment

1. Start Auto RM.
2. Observe Cdyn.
3. Observe vital signs.

E. Post recruitment

1. Change to mode of choice e.g. PRVC, PC, VC.
2. Lower the PC above PEEP (ΔP) or the tidal volume to achieve the optimal VT/PBW (ml/kg).
3. Readjust the alarm limits for PEEP and Ppeak.

Biography: Dr. Carlos Ferrando

Anesthesiologist. MD, PhD, DESA. Head of Surgical ICM, University Clinic Hospital, Barcelona. CIBER Enfermedades Respiratorias. ISCIII, Madrid.

- National and international speaker, 46 congresses so far, all related to mechanical ventilation.
- 40 PubMed publications (18 of them as first author).
- Has worked in 20 international funded research projects, as a research collaborator and as a principal investigator.
- Has edited seven books on topics related to respiratory physiology and pathophysiology, mechanical ventilation, research in anesthesiology, and quality in health. Also, authored 47 book chapters.
- Currently leading a research group focusing on strategies to optimize and individualized intraoperative anesthesia machine management, etc.



Learn more

Watch the 2 min video where Dr. Carlos Ferrando explains why lung recruitment is so important for all patients:
www.getinge.com/whylungrecruitment



References

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2. Lucangelo et al. *J Clin Monit Comput*. 2016 Ball et al. *Best Pract Res Clin Anaesthesiol* 29 (2015) 285-299 Canet et al. *Anesthesiology* 2010 Dec;113(6):1338-50. *Curr Open Anesthesiol* 2012, 25:1-10.
3. Lindberg P, Gunnarsson L, Tokics L, et al. Atelectasis and lung function in the postoperative period. *Acta Anaesthesiol Scand* 1992;36:546-53.
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Further reading

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2. Ferrando C, Belda FJ. New frontiers: art and innovation for intraoperative ventilatory management. *Minerva Anesthesiol*. 2017 Oct;83(10):1007-1009.
3. Ferrando C, Tusman G, Suarez-Sipmann F, et al. Individualized lung recruitment maneuver guided by pulse-oximetry in anesthetized patients undergoing laparoscopy: a feasibility study. *Acta Anaesthesiol Scand*. 2018 May;62(5):608-619.
4. Tusman G, Acosta C, Böhm SH, et al. Postural lung recruitment assessed by lung ultrasound in mechanically ventilated children. *Crit Ultrasound J* (2017) 9:22 DOI 10.1186/s13089-017-0073-0.



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