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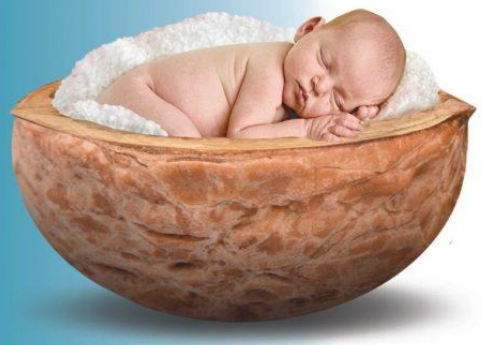

Lung Volume optimization

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Regione Lombardia
ASST Fatebenefratelli Sacco

Conflict of interest statement:

Dr Lista has received honoraria for lectures from Chiesi, Draeger and Vyaire Company. None of these Companies had any input into the content of this presentation

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Mechanisms of ventilator-induced lung injury in premature infants

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Mechanical ventilation in premature infants may injure the lungs or exacerbate the pre-existing condition that led to the need for mechanical ventilation. Ventilator-induced lung injury (VILI) may be associated with alveolar structural damage, pulmonary oedema, inflammation, and fibrosis. This injury is not uniform and is associated with surfactant dysfunction. Recovery from VILI includes clearance of pulmonary oedema and alveolar structural repair. Mechanisms of VILI include high airway pressure (barotrauma), large gas volumes (volutrauma), alveolar collapse and re-expansion (atelectotrauma), and increased inflammation (biotrauma). Injury to the lung may lead to other organ dysfunction. The premature lung is more susceptible to VILI, and lung injury may exacerbate the disturbance of lung development that occurs after birth.

Therapies targeting specific processes in lung injury, and which complement the protective ventilator management strategies to avoid atelectotrauma and lung overdistension are an area of active research.

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Key words: neonate, lung injury, CLD, development, ventilator, infant

Table 1. Mechanisms of VILI

Barotrauma
Volutrauma
Atelectotrauma
Biotrauma
Rheotrauma

Partially modified

Intensive Care Med (1992) 18:319–321

Intensive Care Medicine
© Springer-Verlag 1992

Editorial

Open up the lung and keep the lung open

B. Lachmann

Department of Anesthesiology, Erasmus University Rotterdam, The Netherlands

Since its introduction into clinical use more than 40 years ago artificial ventilation has proven to be a life-saving method of therapy in intensive care. Yet, it has remained a topic of much discussion and controversy because artificial ventilation involves a disturbance to normal respiratory and cardiovascular function.

It is an established fact that artifical ventilation, especially with large tidal volumes and high peak inspiratory pressures, leads to a decrease in lung compliance and dysfunction of gas exchange. Of even greater importance is the realization that ventilation itself can lead to formation of atelectasis, pulmonary edema, pneumonitis and fibrosis (for review see [1–4]); that is why the adult respiratory distress syndrome (ARDS) may be, in part, a product of our therapy – rather than the progression of the underlying disease.

To date no adequate explanation of the pathophysiologic basis of these changes caused by artificial ventilation has been documented. The main contributing factors which emerge from almost all the above-mentioned references seem to be the ventilatory modes which fail to prevent partial (or complete) end-expiratory lung collapse combined with high peak inspiratory pressures.

In this issue Sjöstrand's group, using an animal model of ARDS induced by surfactant depletion, applied five established ventilator modes, adjusting either volume or pressure at preset frequencies to keep end-expiratory alveolar pressure at about 16 cmH_2O and $PaCO_2$ constant (±4 kPa). From their study the following three remarkable results emerge:

1. To open up partially collapsed lungs ventilated in their control mode, a peak pressure of 55 cmH_2O (= opening pressure) in combination with an end-expiratory alveolar pressure of about 16 cmH_2O, resulting in a pressure amplitude of approximately 40 cmH_2O, had to be applied for 5–10 min.
2. After opening the lungs ($PaO_2 > 50$ kPa) they could then be adequately ventilated (PaO_2 and $PaCO_2$ remained stable) with pressure amplitudes of only 16 to 23 cmH_2O in those ventilator modes which created intrinsic PEEP.
3. In the volume controlled mode, with an external PEEP of 8 cmH_2O, a pressure amplitude of almost twice that required by modes creating internal PEEP was necessary for adequate ventilation and even then the lungs could not be kept completely open (PaO_2 about 40 kPa).

Why is it so important to ventilate lungs with as small as possible pressure amplitude?

More than twenty years ago Mead et al. stated that: "at a transpulmonary pressure of 30 cmH_2O, the pressure tending to expand an atelectatic region surrounded by a fully expanded lung would be approximately 140 cmH_2O" [5]. Such forces may well be the major cause of structural damage (especially to bronchiolar epithelium, alveolar epithelium and capillary endothelium) and may not only be the basis for formation of hyaline membranes but may also cause the release of mediators from the disrupted parenchyma – triggering the pathophysiological mechanisms of ARDS [6].

During ventilation of patients with ARDS, who almost always have atelectatic lung regions, pressure differences of 30 cmH_2O or higher are quite common. We have to understand, however, that it is not the 30 cmH_2O pressure difference that damage the lungs but rather the resulting shear forces of more than 140 cmH_2O which are responsible for the barotrauma.

Sjöstrand's group does not present morphological data, but from other experiments related to different modes of artifical ventilation in ARDS lungs (see referred reviews) it was clearly demonstrated that lungs ventilated with modes which did not prevent end-expiratory alveolar collapse, thus creating shear forces, showed more severe morphologic damage (and lower arterial PaO_2) compared to modes which kept the entire lungs open during the whole respiratory cycle.

It must be concluded that in order to prevent lung damage due to high shear forces between open and closed lung units only ventilation modes which result in the smallest possible pressure amplitude should be used.

Opening pressure

Adequate ventilation

Role of PEEP

To prevent lung damage

Eur J Pediatr
DOI 10.1007/s00431-017-2984-y

REVIEW

Achieving and maintaining lung volume in the preterm infant: from the first breath to the NICU

Gianluca Lista[1] · Andrés Maturana[2] · Fernando R. Moya[3]

What is Known:

- *Experimental and clinical studies have shown that the transition from fetal to adult type cardiorespiratory circulation needs an adequate lung ventilation. An appropriate management in the delivery room should lead to the achievement of an early FRC, and through the following steps, the neonatologist should aim at maintaining an adequate lung volume.*
- *Literature underlines the importance of a respiratory tailored management of preterm infants during the whole NICU stay to maintain the benefits of a successful postnatal adaption.*

What is New:

- *Herewith, we describe the most relevant and recent interventions which can be performed from the delivery room to the NICU stay to guarantee an adequate tradition to postnatal life and an effective cardiorespiratory stability.*

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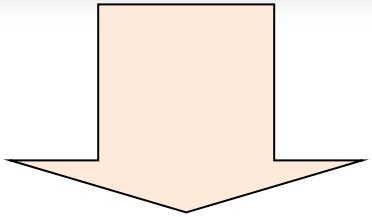
www.nature.com/jp

STATE-OF-THE-ART

Delivery room interventions to prevent bronchopulmonary dysplasia in extremely preterm infants

EE Foglia[1,2], EA Jensen[1,2] and H Kirpalani[1,2]

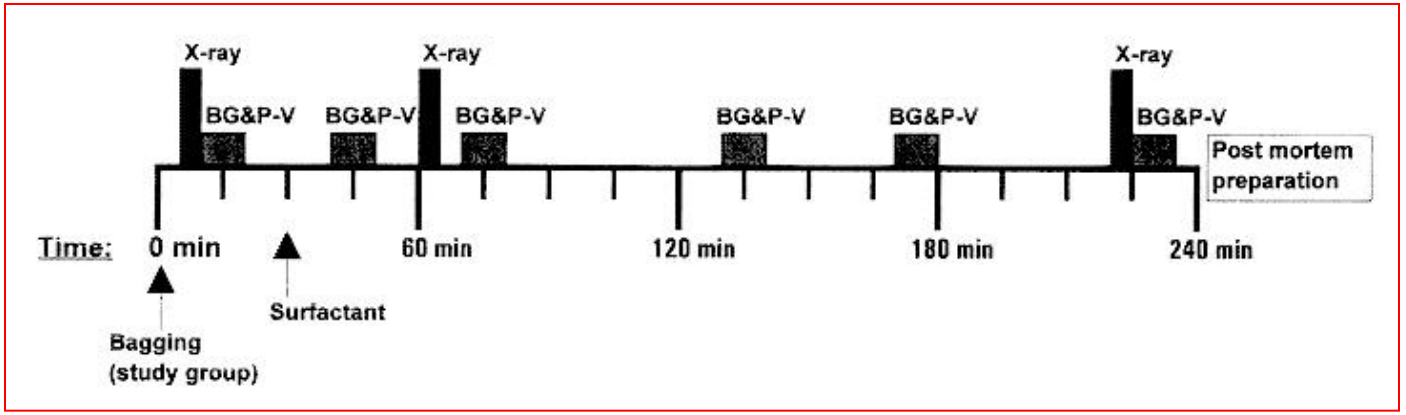


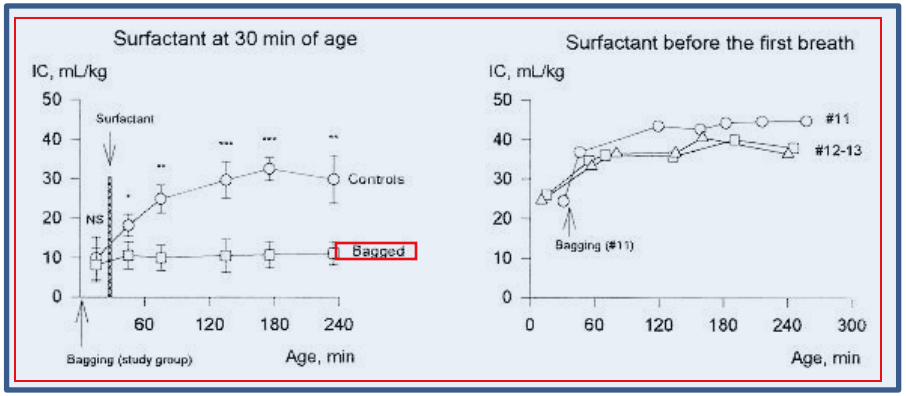
DR management of lung aeration

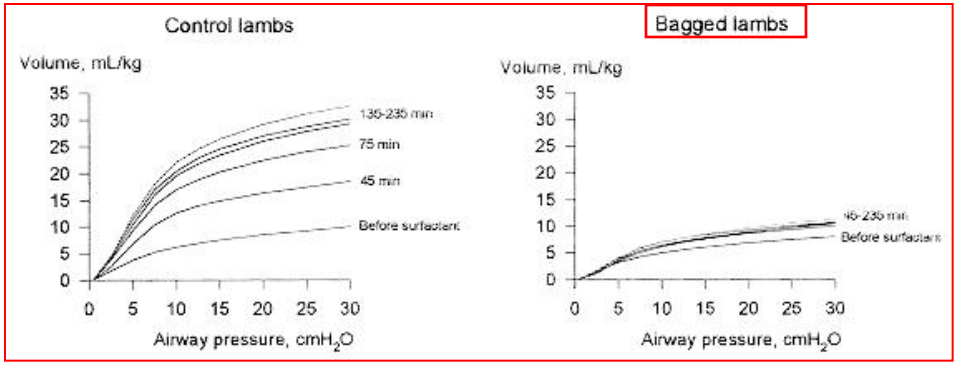
Manual Ventilation with a Few Large Breaths at Birth Compromises the Therapeutic Effect of Subsequent Surfactant Replacement in Immature Lambs

Lars J Björklund, Jonas Ingimarsson, Tore Curstedt, Joseph John, Bengt Robertson, Olof Werner and Carsten T

Pediatric Research (1997) 42, 348–355







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PLoS one

Initiation of Resuscitation with High Tidal Volumes Causes Cerebral Hemodynamic Disturbance, Brain Inflammation and Injury in Preterm Lambs

Graeme R. Polglase[1,2*], Suzanne L. Miller[1,2], Samantha K. Barton[1], Ana A. Baburamani[1], Flora Y. Wong[1], James D. S. Aridas[1], Andrew W. Gill[3], Timothy J. M. Moss[1,2], Mary Tolcos[1], Martin Kluckow[4,5], Stuart B. Hooper[1,2,5]

1 The Ritchie Centre, Monash Institute of Medical Research, Monash University, Clayton, Victoria, Australia, 2 Department of Obstetrics and Gynecology, Monash University, Clayton, Victoria, Australia, 3 Centre for Neonatal Research and Education, School of Women's and Infants' Health, The University of Western Australia, Crawley, Western Australia, Australia, 4 Department of Neonatal Medicine, Royal North Shore Hospital and University of Sydney, Sydney, New South Wales, Australia

Abstract

Aims: Preterm infants can be inadvertently exposed to high tidal volumes (V_T) in the delivery room, causing lung inflammation and injury, but little is known about their effects on the brain. The aim of this study was to compare an initial 15 min of high V_T resuscitation strategy to a less injurious resuscitation strategy on cerebral haemodynamics, inflammation and injury.

Methods: Preterm lambs at 126 d gestation were surgically instrumented prior to receiving resuscitation with either: 1) High V_T targeting 10–12 mL/kg for the first 15 min (n = 6) or 2) a protective resuscitation strategy (Prot V_T), consisting of prophylactic surfactant, a 20 s sustained inflation and a lower initial V_T (7 mL/kg; n = 6). Both groups were subsequently ventilated with a V_T 7 mL/kg. Blood gases, arterial pressures and carotid blood flows were recorded. Cerebral blood volume and oxygenation were assessed using near infrared spectroscopy. The brain was collected for biochemical and histologic assessment of inflammation, injury, vascular extravasation, hemorrhage and oxidative injury. Unventilated controls (UVC; n = 6) were used for comparison.

Results: High V_T lambs had worse oxygenation and required greater ventilatory support than Prot V_T lambs. High V_T resulted in cerebral haemodynamic instability during the initial 15 min, adverse cerebral tissue oxygenation index and cerebral vasoparalysis. While both resuscitation strategies increased lung and brain inflammation and oxidative stress, High V_T resuscitation significantly amplified the effect ($p = 0.014$ and $p < 0.001$). Vascular extravasation was evident in the brains of 60% of High V_T lambs, but not in UVC or Prot V_T lambs.

Conclusion: High V_T resulted in greater cerebral haemodynamic instability, increased brain inflammation, oxidative stress and vascular extravasation than a Prot V_T strategy. The initiation of resuscitation targeting Prot V_T may reduce the severity of brain injury in preterm neonates.

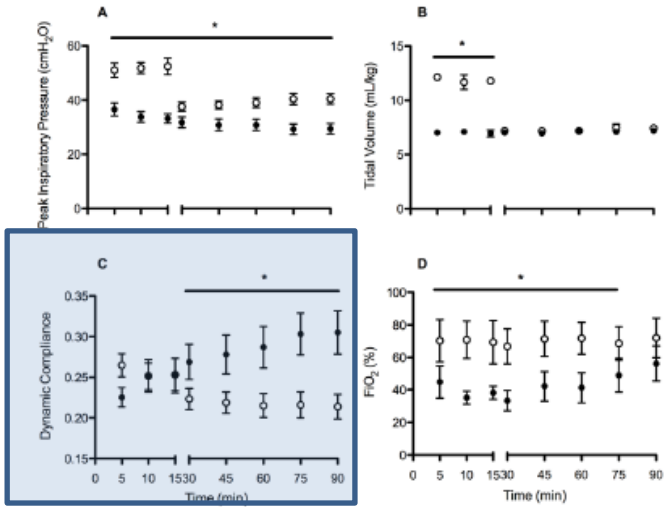

Figure 1. Peak inspiratory pressure (A), tidal volume (B), dynamic compliance (C) and the fraction of inspired oxygen (FiO2; D) in High V_T (open circles) and Prot V_T (closed circles) lambs. *p<0.05 High V_T vs. Prot V_T.
doi:10.1371/journal.pone.0039535.g001

between the groups (p = 0.271). The number of 4HNE-positive cells, indicative of oxidative injury, was significantly higher in High V_T lambs within the periventricular white matter compared to UVC (p<0.001) and showed a strong trend to be greater than Prot V_T lambs (p = 0.054). There was no difference observed in the subcortical white matter (p = 0.13; Table 1).

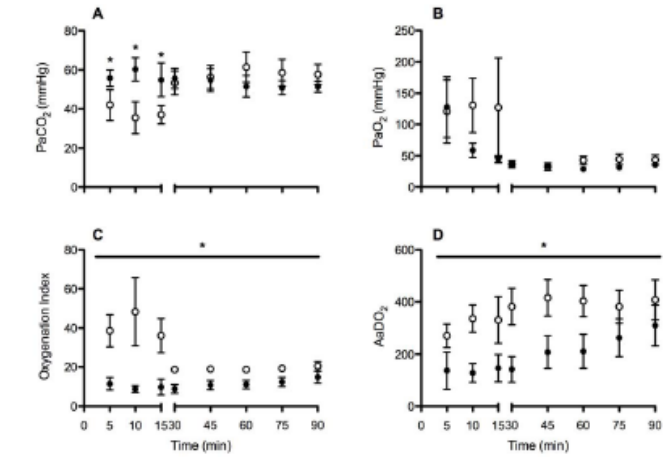

Figure 2. The partial pressure of arterial (Pa) carbon dioxide (CO_2; A), oxygen (O_2; B), oxygenation index (C) and the alveolar-arterial difference in oxygen ($AaDO_2$; D) in High V_T (open circles) and Prot V_T (closed circles) lambs. *p<0.05 High V_T vs. Prot V_T.
doi:10.1371/journal.pone.0039535.g002

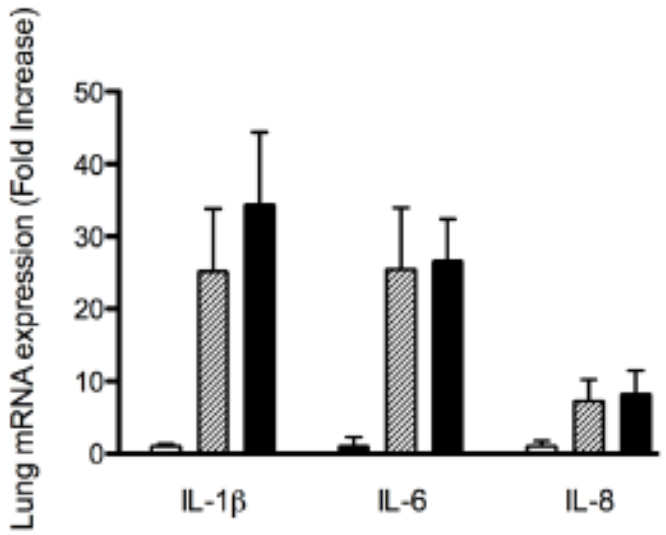

Figure 5. Lung pro-inflammatory mRNA cytokine expression of interleukin (IL)-1β, IL-6 and IL-8 in unventilated controls (open bars), Prot V_T (shaded bars) and High V_T (black bars) lambs. Values are expressed relative to UVC. Resuscitation, irrespective of the strategy, increased lung inflammation. *p<0.05 vs UVC.
doi:10.1371/journal.pone.0039535.g005

= unventilated

= Prot Vt

= high Vt

= Prot Vt

= high Vt

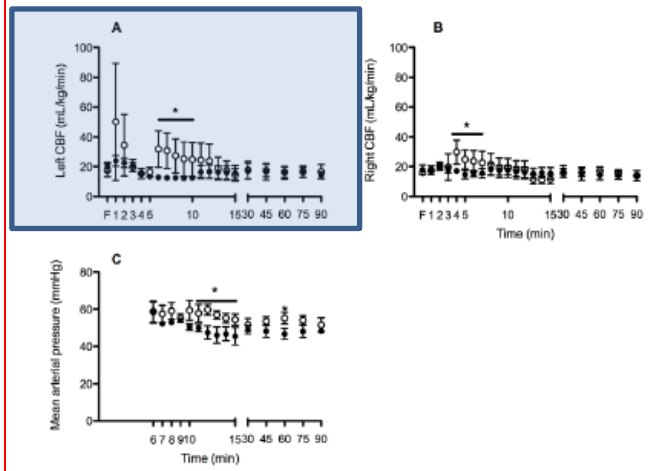

Figure 3. Left (A) and right (B) carotid blood flow (CABF) and mean arterial pressure (C) in High V_T (open circles) and Prot V_T (closed circles) lambs. *p<0.05 High V_T vs. Prot V_T.
doi:10.1371/journal.pone.0039535.g003

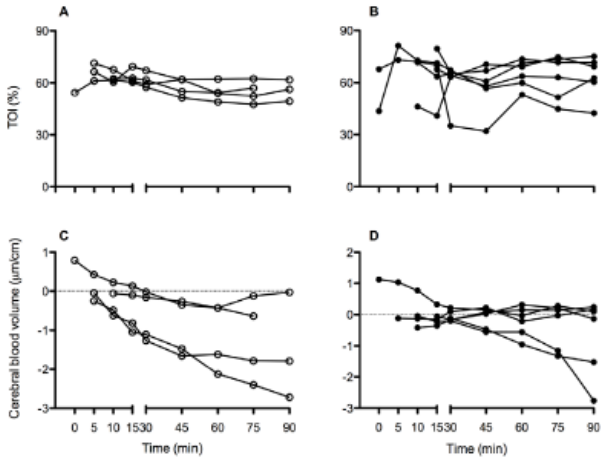

Figure 4. Tissue oxygenation index (TOI; A & B) and cerebral blood volume (C & D) in High V_T (open circles) and Prot V_T (closed circles) lambs. Values are derived using spatially resolved near infrared spectroscopy. Note the greater variability in TOI within the first 15 min during High V_T lambs (B) compared to Prot V_T. Cerebral vascular vasoparalysis is evident in 4 of 5 High V_T lambs by the maintenance of near stable cerebral blood volume (D).
doi:10.1371/journal.pone.0039535.g004

Table 1. Assessment of brain injury.

Group	UVC (n = 6)			Prot V_T (n = 5)			High V_T (n = 5)		
Incidence and severity of injury (%)	**Incidence**	**Mild**	**Severe**	**Incidence**	**Mild**	**Severe**	**Incidence**	**Mild**	**Severe**
Gross Anatomical Injury									
Periventricular white matter	0	0	0	40	20	20	20	20	0
Subcortical white matter	12	0	12	40	40	40	40	20	20
Lipid Peroxidation									
Periventricular white matter (cells/mm^2)	245±99			412±41			580±60*#		
Subcortical white matter (cells/mm^2)	271±73			393±38			402±39		
Vascular protein extravasation									
Periventricular & subcortical white matter (%)	0			0			60*#		
Infiltrating inflammatory cells									
Periventricular white matter (cells/mm^2)	120±37			205±26			211±65		
Subcortical white matter (cells/mm^2)	196±58			536±40			728±242*		

Incidence and severity of gross anatomical brain injury expressed as % of the lambs displaying evidence of mild or severe injury. *Indicates significant difference between High V_T and UVC. #Indicates significant difference between High V_T and Prot V_T.
doi:10.1371/journal.pone.0039535.t001

In summary, this study has shown that resuscitation increases brain inflammation and oxidative stress, but an initial high V_T resuscitation strategy further exacerbated cerebral hemodynamic instability, brain inflammation and injury. This study highlights the critical role that the initial respiratory support has on the development of brain inflammation and injury, and the requirement for better monitoring of delivered tidal volumes to preterm infants in the delivery room. It also demonstrates that brain injury can be seen within 90 minutes of the onset of an injurious stimulus, and the severity of brain injury can be reduced by protective resuscitation strategies in the delivery room.

● = Prot Vt

○ = high Vt

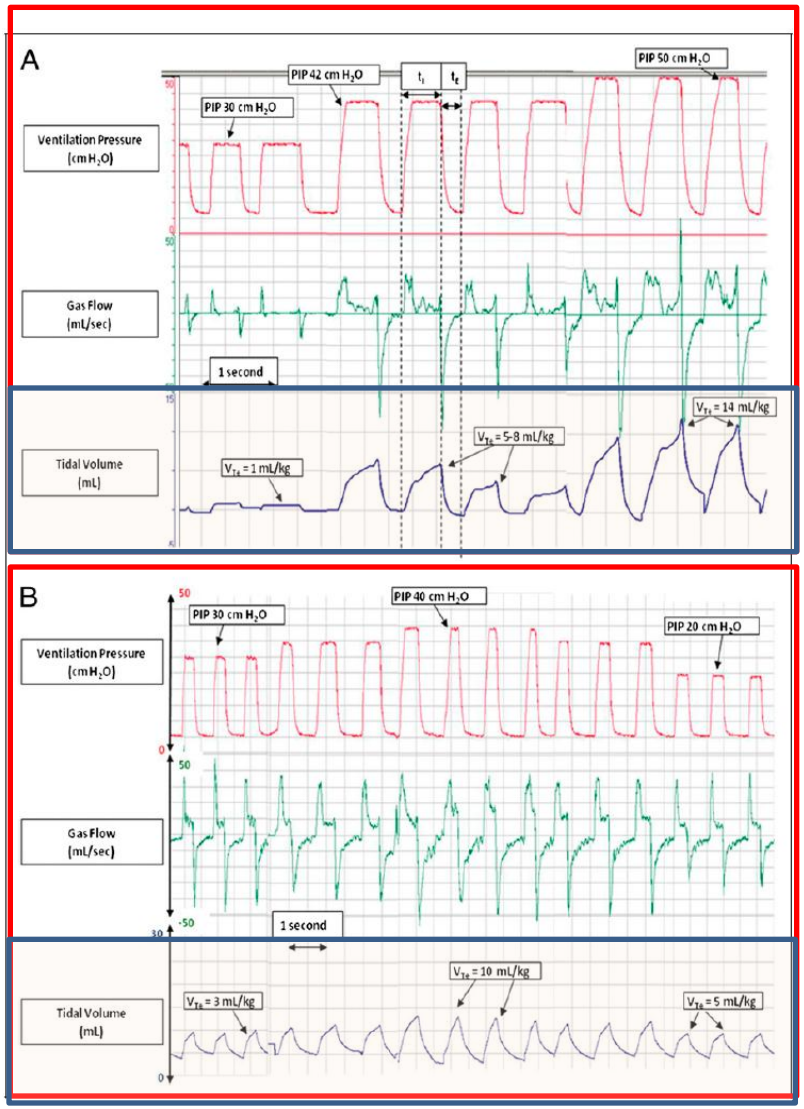

Figure 2. In panel A, the clinical team is guiding positive pressure ventilation by observing chest rise compared with panel B where a respiratory function monitor is used to guide expired tidal volume (V_{Te}) delivery. Initially, no chest rise is observed, the inflation and expiratory flow curves are small, and the measured V_{Te} is ~1 mL/kg. The clinical team is increasing the peak inflation pressure (PIP) to 42 cm H_2O, which results in an increase in V_{Te} to 5 to 8 mL/kg; however, there was still no chest rise visible. The clinical team continued to increase the PIP to 50 cm H_2O PIP, which resulted in an increase of V_{Te} to 14 mL/kg and visible chest rise. In comparison, in B, the initial V_{Te} was 3 mL/kg. After an increase in PIP, V_{Te} increased to 10 mL/kg. After the clinical team recognized the large V_{Te}, the PIP was reduced to 20 cm H_2O, which resulted in a decrease in the delivered V_{Te} to ~5 mL/kg.

Improving Assessment During Noninvasive Ventilation in the Delivery Room
Gianluca Lista, Georg M. Schmölzer and Colm P.F. O'Donnell
Neoreviews 2012;13;e364
DOI: 10.1542/neo.13-6-e364

Respiratory Function Monitor (RFM)

Background: SI and transition

- SI and PEEP allow an early FRC and uniformity of lung areation (te Pas A et al , Pediatric Research 2009)
- SI improves the respiratory and cardiovascular transition at birth in preterm lambs (Sobotka K et al, Pediatric Research 2011)
- SI improves speed of circulatory rate and lung compliance in near-term asphyxiated lambs (Klingenbergr C et al Arch Dis Child Fetal Neonatal

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PLoS one

Initiation of Resuscitation with High Tidal Volumes Causes Cerebral Hemodynamic Disturbance, Brain Inflammation and Injury in Preterm Lambs

Graeme R. Polglase[1,2*], Suzanne L. Miller[1,2], Samantha K. Barton[1], Ana A. Baburamani[1], Flora Y. Wong[1], James D. S. Aridas[1], Andrew W. Gill[3], Timothy J. M. Moss[1,2], Mary Tolcos[1], Martin Kluckow[4,5], Stuart B. Hooper[1,2,5]

1 The Ritchie Centre, Monash Institute of Medical Research, Monash University, Clayton, Victoria, Australia, 2 Department of Obstetrics and Gynecology, Monash University, Clayton, Victoria, Australia, 3 Centre for Neonatal Research and Education, School of Women's and Infants' Health, The University of Western Australia, Crawley, Western Australia, Australia, 4 Department of Neonatal Medicine, Royal North Shore Hospital and University of Sydney, Sydney, New South Wales, Australia

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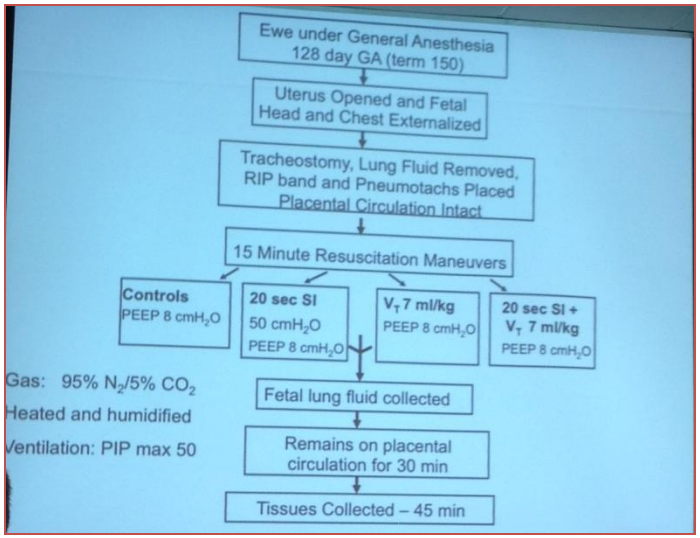
Conclusion: High V_T resulted in greater cerebral haemodynamic instability, increased brain inflammation, oxidative stress and vascular extravasation than a Prot V_T strategy. The initiation of resuscitation targeting Prot V_T may reduce the severity of brain injury in preterm neonates.

Sustained Inflation at birth did not protect preterm fetal sheep from lung injury

[1,2] Noah H. Hillman
[3] Matthew W. Kemp
[3,4,5] Peter B. Noble
[2,3] Suhas G. Kallapur
[2,3] Alan H. Jobe

Am J Physiol Lung Cell Mol Physiol (July 19, 2013).



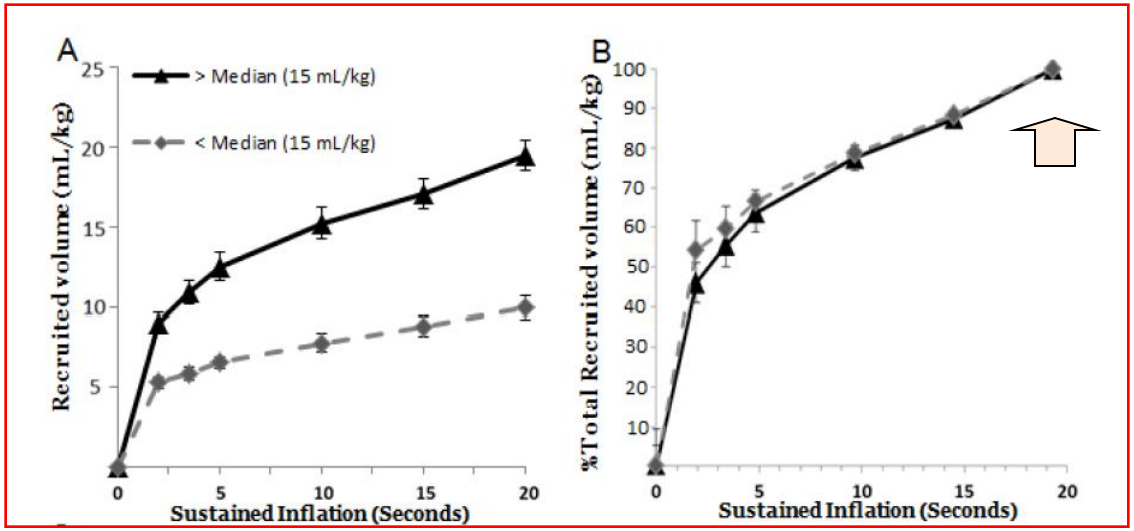


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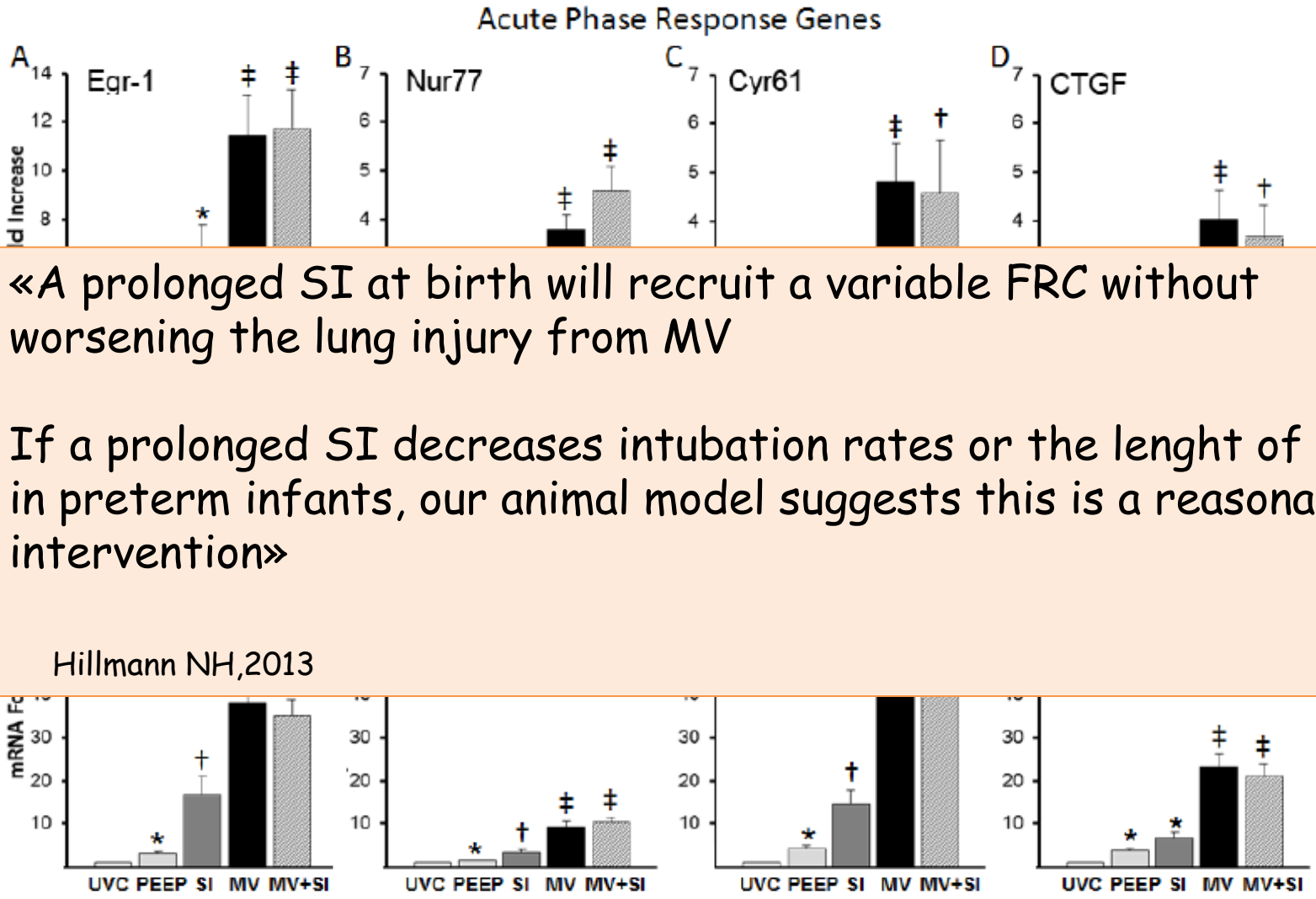
Table 2: Proteins released into fetal lung fluid and bronchoalveolar lavage fluids

Group	HSP70			HSP60	Total Protein		
	FLF 15m ng/ml	FLF 45m ng/ml	BALF ng/kg	BALF ng/kg	FLF 15m ng/ml	FLF 45m ng/ml	BALF ng/kg
PEEP	5±0.4	33±4	105±5	21±7	2±0.4	8±3	42±4
SI	36±3*	45±6	105±7	33±5	8±1	15±2	46±8
MV	42±2*	50±3*	150±10†	316±42†	12±1†	26±1†	94±7†
MV + SI	48±3†	51±3*	156±8†	304±50†	13±1†	26±1†	100±11†

Values: Mean±SEM * p<0.05 vs PEEP † p<0.05 vs PEEP and SI groups



- «A prolonged SI at birth will recruit a variable FRC without worsening the lung injury from MV
- If a prolonged SI decreases intubation rates or the lenght of MV in preterm infants, our animal model suggests this is a reasonable intervention»

Hillmann NH,2013

Part 7: Neonatal Resuscitation

2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations

Jeffrey M. Perlman, Co-Chair*; Jonathan Wyllie, Co-Chair*; John Kattwinkel; Myra H. Wyckoff; Khalid Aziz; Ruth Guinsburg; Han-Suk Kim; Helen G. Liley; Lindsay Mildenhall; Wendy M. Simon; Edgardo Szyld; Masanori Tamura; Sithembiso Velaphi; on behalf of the Neonatal Resuscitation Chapter Collaborators

(*Circulation*. 2015;132[suppl 1]:S204–S241.

Treatment Recommendation

We **suggest against** the routine use of initial SI (greater than 5 seconds duration) for preterm infants without spontaneous respirations immediately after birth, but an SI may be considered in individual clinical circumstances or research settings (weak recommendation, low-quality evidence).

Resuscitation xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Resuscitation

journal homepage: www.elsevier.com/locate/resuscitation

ELSEVIER

EUROPEAN RESUSCITATION COUNCIL

European Resuscitation Council Guidelines for Resuscitation 2015 Section 7. Resuscitation and support of transition of babies at birth

Jonathan Wyllie[a,*], Jos Bruinenberg[b], Charles Christoph Roehr[d,e], Mario Rüdiger[f], Daniele Trevisanuto[c], Berndt Urlesberger[g]

Cochrane Library

Cochrane Database of Systematic Reviews

Sustained versus standard inflations during neonatal resuscitation to prevent mortality and improve respiratory outcomes (Review)

Bruschettini M, O'Donnell CPF, Davis PG, Morley CJ, Moja L, Zappettini S, Calevo MG

Cochrane Database of Systematic Reviews 2017, Issue 7. Art. No.: CD004953.

Analysis 1.8. Comparison 1 Use of initial sustained inflation vs standard inflations in newborns receiving resuscitation with no chest compressions, Outcome 8 Duration of mechanical ventilation.

Review: Sustained versus standard inflations during neonatal resuscitation to prevent mortality and improve respiratory outcomes

Comparison: 1 Use of initial sustained inflation vs standard inflations in newborns receiving resuscitation with no chest compressions

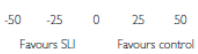
Outcome: 8 Duration of mechanical ventilation

Study or subgroup	SLI N	SLI Mean(SD)[days]	control N	control Mean(SD)[days]	Mean Difference IV,Fixed,95% CI	Weight	Mean Difference IV,Fixed,95% CI
Mercadante 2016	93	3.5 (2.8)	92	0.08 (0)			Not estimable
Lindner 2005	28	15.3 (20.5)	30	14.6 (17.9)		0.9 %	0.70 [-9.23, 10.63]
Jiravisitkul 2017	42	1.5 (3.35)	37	4.13 (5.65)		20.2 %	-2.63 [-4.71, -0.55]
Schwaberger 2015	20	0.75 (2.02)	20	1.9 (3.42)		29.0 %	-1.15 [-2.89, 0.59]
Ngan 2017	76	7.54 (3.8)	86	16.58 (4.8)		49.9 %	-9.04 [-10.37, -7.71]
Total (95% CI)	**259**		**265**			**100.0 %**	**-5.37 [-6.31, -4.43]**

Heterogeneity: Chi² = 60.07, df = 3 (P<0.00001); I² =95%

Test for overall effect: Z = 11.23 (P < 0.00001)

Test for subgroup differences: Not applicable



Authors' conclusions

Sustained inflation was not better than intermittent ventilation for reducing mortality in the delivery room and during hospitalisation. The number of events across trials was limited, so differences cannot be excluded. When considering secondary outcomes, such as need for intubation, need for or duration of respiratory support, or bronchopulmonary dysplasia, we found no evidence of relevant benefit for sustained inflation over intermittent ventilation. The duration of mechanical ventilation was shortened in the SLI group. This result should be interpreted cautiously, as it can be influenced by study characteristics other than the intervention. Future RCTs should aim to enrol infants who are at higher risk of morbidity and mortality, should stratify participants by gestational age, and should provide more detailed monitoring of the procedure, including measurements of lung volume and presence of apnoea before or during the SLI.

……SI and its definitive role (efficacy and safety) in the DR : it is still under investigation

Effect of sustained inflation vs. stepwise PEEP strategy at birth on gas exchange and lung mechanics in preterm lambs

David G. Tingay[1–4], Risha Bhatia[1,3,4], Georg M. Schmölzer[1,3,5], Megan J. Wallace[5], Valerie A. Zahra[5] and Peter G. Davis[1,3,6]

Pediatric RESEARCH Volume 75 | Number 2 | February 2014

BACKGROUND: **optimal technique for lung recruitment at birth**?

OBJECTIVE: To compare 3 ventilation strategies at birth, and the timing of surfactant delivery, in an extremely preterm lamb model.

DESIGN/METHODS: 127d GA lambs (n=8/group, mean BW 2.97 kg) ventilated for 70-min with one of three strategies from delivery:

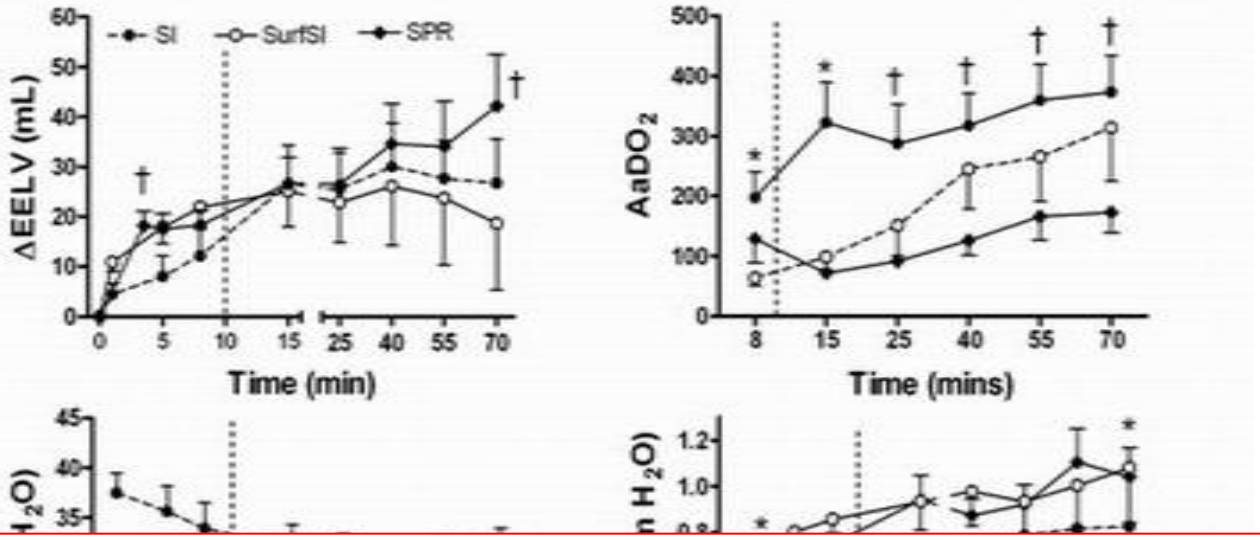
1.Sustained Inflation (SI): 20-sec 35cmH_2O SI (then PPV+Targeted TV (TTV;7mL/kg, PEEP 6cmH_2O, FiO_2 0.21) and surfactant at 10-min. FiO_2 and TTV adjusted to maintain SpO_2 88-92% and $PaCO_2$ 45-55mmHg.

2.SurfSI: Pre-delivery surfactant otherwise as pre SI.

3.Stepwise PEEP recruitment (SPR): PEEP increased by 2cmH_2O every 10 inflations from 4 to 20 cmH_2O (using PPV+TTV then decreased to the PEEP resulting in maximal C_{rs} (Mean (SD) PEEP 7.9(1.6)cmH_2O). Surfactant administered at 10-min.

Measurements :Regular BG analysis. SpO_2, PAW, C_{rs}, total and regional V_T and end-expiratory lung volume (EELV; respiratory inductive plethysmography and EIT-electrical impedance tomography) were recorded for the first 15-min, and with BG analysis .Statistics: ANOVA.

Figure 1. Comparison of Sustained Inflation, with and without pre-delivery surfactant, and a step-wise PEEP strategy applied at birth.



CONCLUSION: An SEP at birth improved gas exchange, lung mechanics, and EEV, without increasing lung injury, compared to the SI strategy used.

† p<0.0001 SPR vs SI (ΔEELV) and p<0.05 ($AaDO_2$); * p<0.05 SPR and SurfSI vs SI; ΔP greater at all time points using SI (p<0.01)

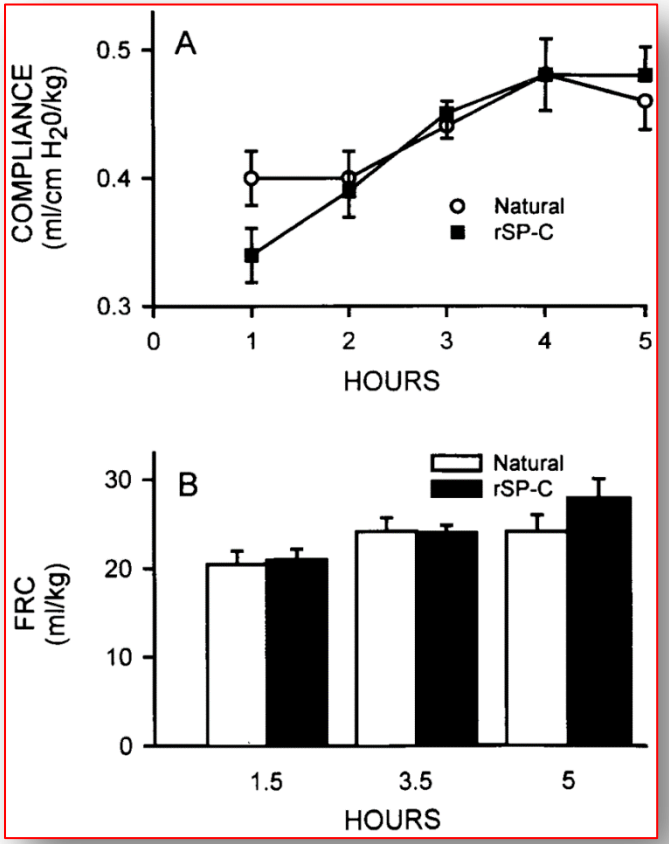
RESULTS: After the recruitment maneuver, SPR and SurfSI resulted in better EELV, *C*rs and AaDO2 compared to SI, with EELV being 18(SD 9)mL/kg after SPR vs 4(6)mL/kg after SI (p<0.0001). *C*rs was 0.22 (0.1)mL/cmH2O greater than SI for both SurfSI and SPR (p<0.05). Surfactant administration generally negated these differences, but, by 70-min SPR again resulted in better AaDO2, *C*rs and EELV compared to SI. SI group required a higher TTV (p=0.0017; ANOVA) to maintain desired PaCO2 range. SI resulted in the least uniform distribution of ventilation.

Lung mechanics after surfactant

MISURA	PRE-SURFATTANTE	POST-SURFATTANTE
DISTENSIBILITÀ	0.500 ± 0.086	0.538 ± 0.099
FRC	9.85 ± 2.10	22.16 ± 3.70 *
A/a O2	3.92 ± 0.70	1.63 ± 0.21 *

Promedio ± SEM
* P < 0.05

Goldsmith et al. *J Pediatr* 1991; 119: 424.



AJ Davis, 1998

Journal of Perinatology (2017) 00, 1–9
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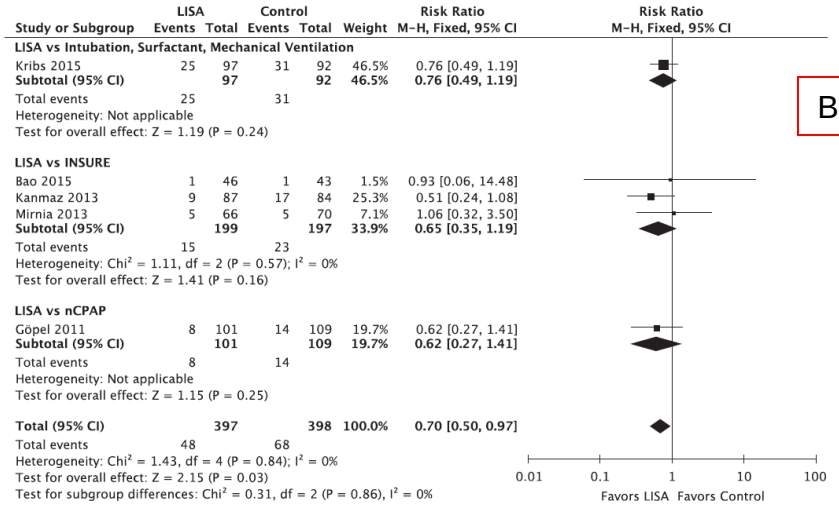
www.nature.com/jp

STATE-OF-THE-ART

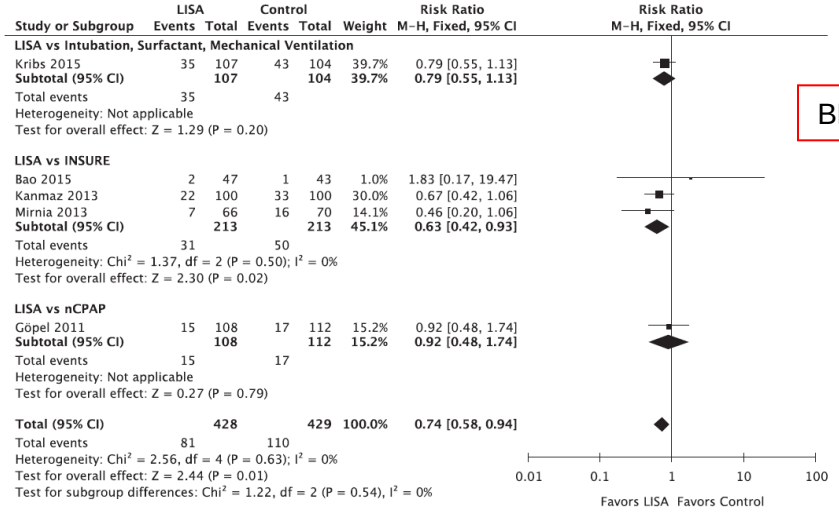
Delivery room interventions to prevent bronchopulmonary dysplasia in extremely preterm infants

EE Foglia[1,2], EA Jensen[1,2] and H Kirpalani[1,2]



BPD

Figure 1. Forrest plot for the outcome of bronchopulmonary dysplasia among survivors, comparing less-invasive surfactant administration (LISA) vs control therapy in extremely preterm infants. CI, confidence interval; INSURE, INtubation, SURfactant administration during brief mechanical ventilation, followed by Extubation; nCPAP, nasal continuous positive airway pressure.

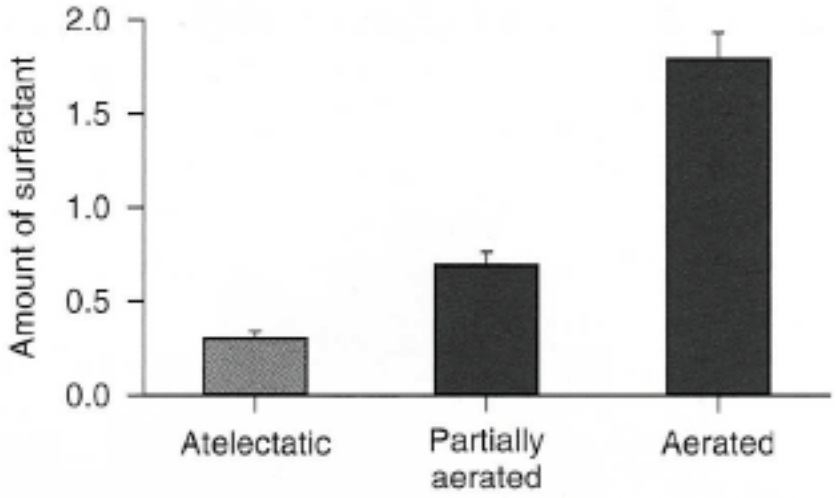


BPD/Death

Figure 2. Forrest plot for the outcome of death or bronchopulmonary dysplasia, comparing less-invasive surfactant administration (LISA) vs control therapy in extremely preterm infants. CI, confidence interval; INSURE, INtubation, SURfactant administration during brief mechanical ventilation, followed by Extubation; nCPAP, nasal continuous positive airway pressure.

…surfactant should be given early (< 2 hrs of life) and modality of administration could influence its effect

Lung aereation and surfactant distribution



Berry et al. ***Am Rev Respir Dis*** 1985; 132: 500.

*Thererefore it may be a role for **Lung recruitment maneuver** before surfactant replacement in all preterm infants at risk for RDS in order to optimize its effect*

Lung Volume Recruitment after Surfactant Administration Modifies Spatial Distribution of Ventilation

Am J Respir Crit Care Med Vol 174. pp 772–779, 2006

Inéz Frerichs, Peter A. Dargaville, Huibert van Genderingen†, Denis R. Morel, and Peter C. Rimensberger

16 newborn piglets with induced ARDS

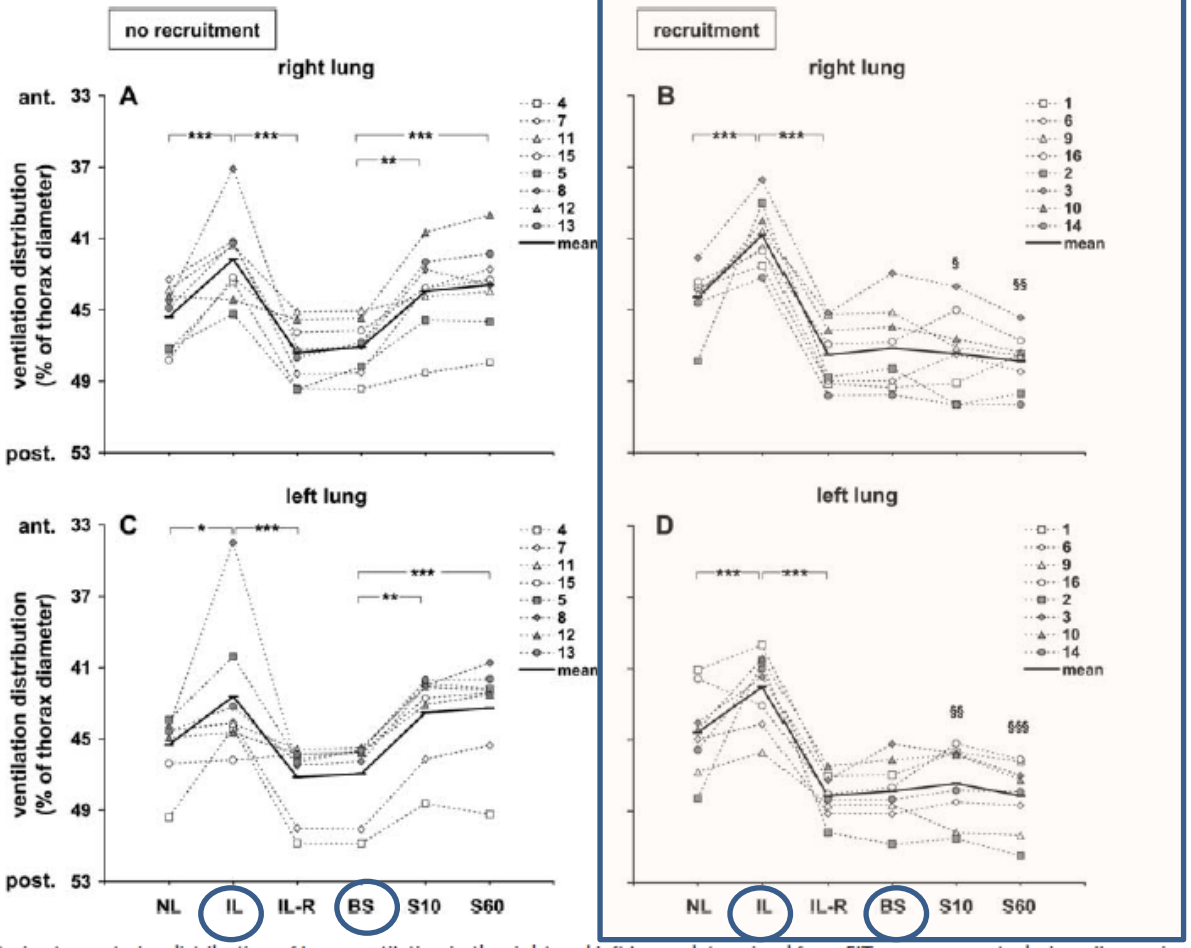
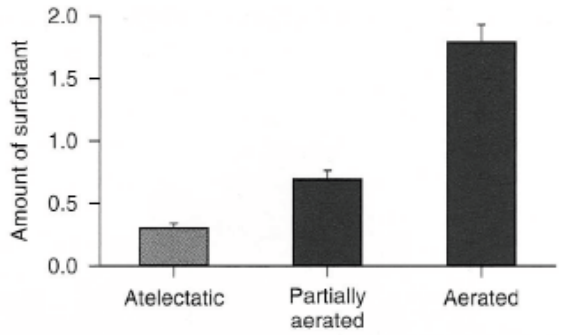


Figure 3. Anterior-to-posterior distribution of lung ventilation in the right and left lungs determined from EIT measurements during all experimental phases. Plots for individual animals and the mean for the experimental group are shown. *Open* and *closed symbols* denote surfactant delivery in the "open" and "closed" lungs, respectively. (*A*) Right lung, no recruitment after surfactant; (*B*) right lung, with recruitment; (*C*) left lung, no recruitment; (*D*) left lung, with recruitment. *Asterisks* above the plot in each panel show statistically significant differences between different experimental phases (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). The *§ symbols* indicate significantly greater ventilation of the dorsal lung regions in the Recruitment group in the postsurfactant period (§$p < 0.05$, §§$p < 0.01$, §§§$p < 0.001$). ant., anterior; post., posterior.

NL = normal lung
IL = injured lung
R = recruitment
BS = before surf
S10-S60 = 10'-60'after S

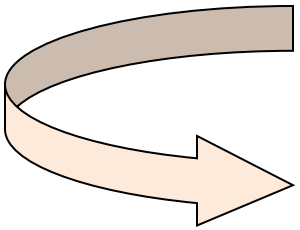
Conclusions: the spatial distribution of ventilation **(greater ventilation)** in the lavaged lung is significantly modified by a R maneuver performed after Surf administration

Lung aereation and surfactant distribution



Berry et al. ***Am Rev Respir Dis*** 1985; 132: 500.

Thererefore it may be a role for 1) ***a first Lung recruitment maneuver*** *(e.g.SLI procedure, stepwise increement of PEEP) before surfactant replacement in all preterm infants at risk for RDS in order to optimize its effect*

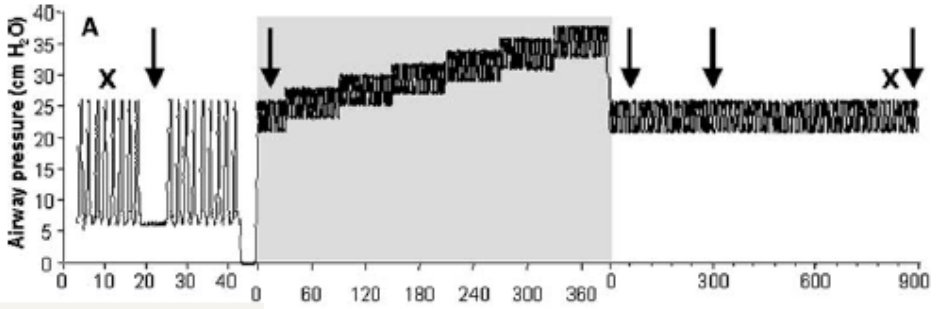


2) ***a second Lung recruitment maneuver*** *(=High lung volume strategy) after surfactant replacement in all preterm infants in mechanical ventilation for RDS to optimize lung volume with minimal VILI*

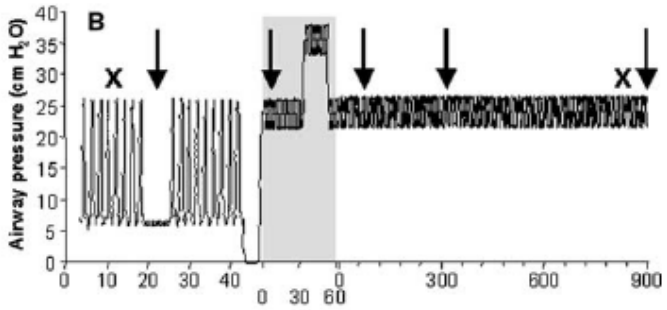
4 lung recruitment methods

(N= 10 piglets, RDS, CMV..then HFOV)

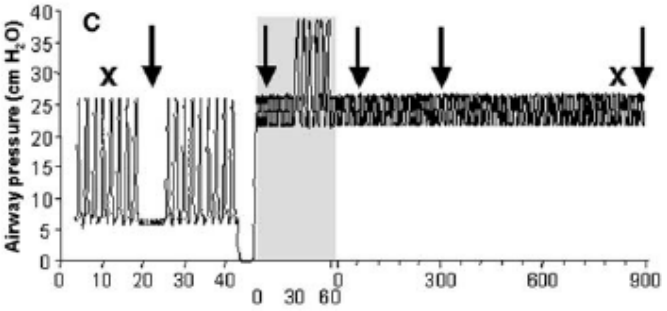
All methods were tested in each animal during HFOV



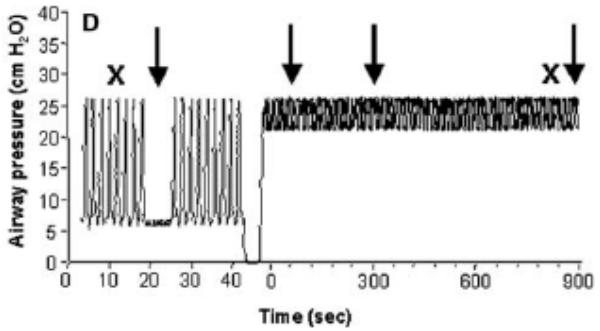
Escalating-step-wise P
Step to PIP= 35 cmH2O in 6’



Sustained dynamic inflation
To a PIP= 35 cmH2O for 20”



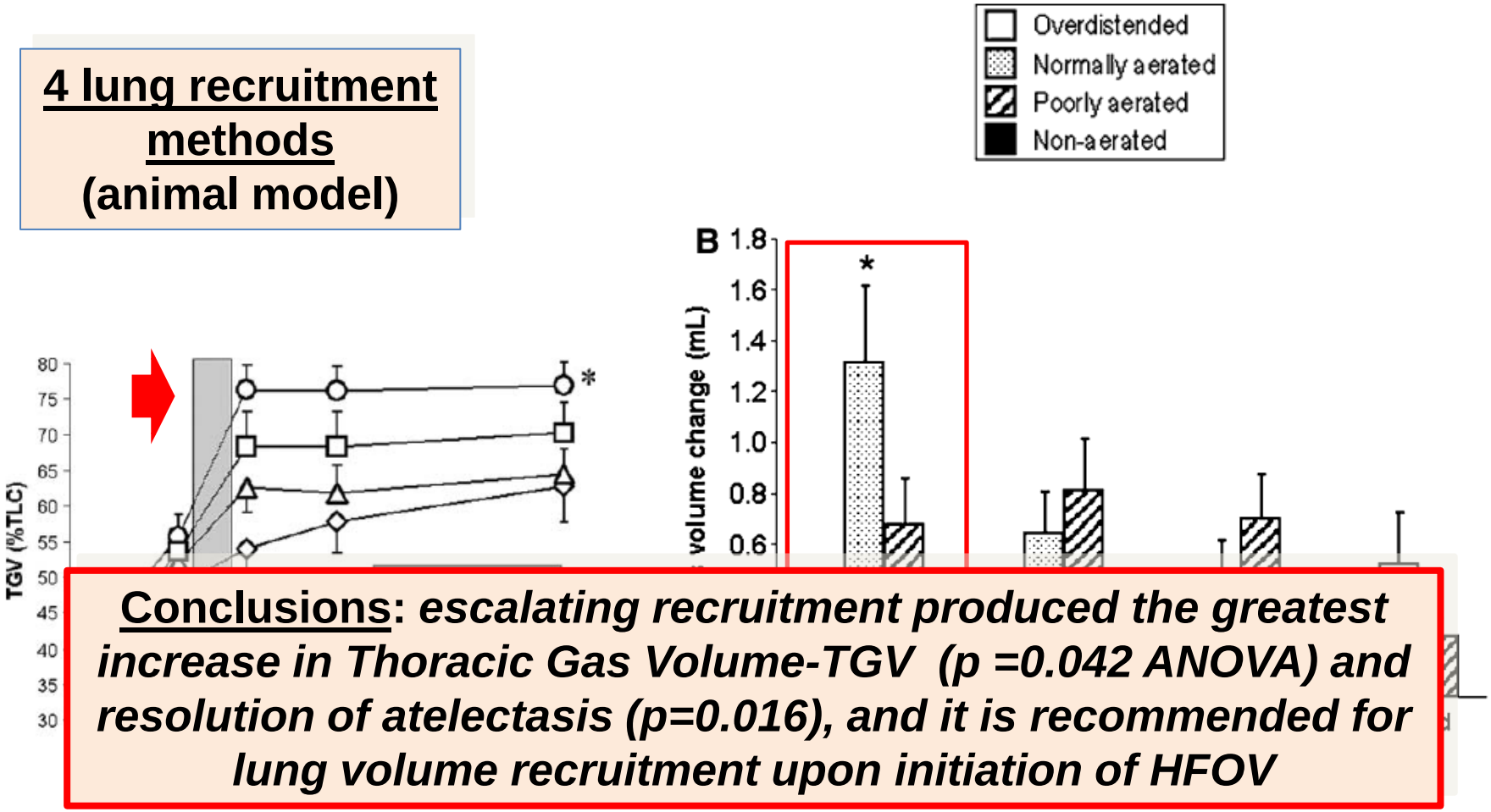
Repeated dynamic Inflation
To a PIP= 35 cmH2O for 1”
x 6 times



Standard MAP set

Pellicano A et al
Comparison of four methods of lung volume recruitment during HFOV. Int Care Med 2009; 35: 1990

4 lung recruitment methods (animal model)

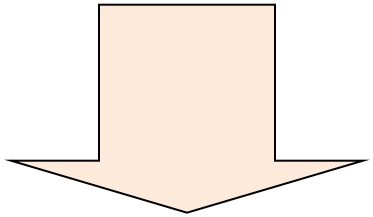


Conclusions: ***escalating recruitment produced the greatest increase in Thoracic Gas Volume-TGV (p =0.042 ANOVA) and resolution of atelectasis (p=0.016), and it is recommended for lung volume recruitment upon initiation of HFOV***

Pellicano A et al
Comparison of four methods of lung volume recruitment during HFOV.
Int Care Med 2009; 35: 1990

TGV= thoracic gas volume

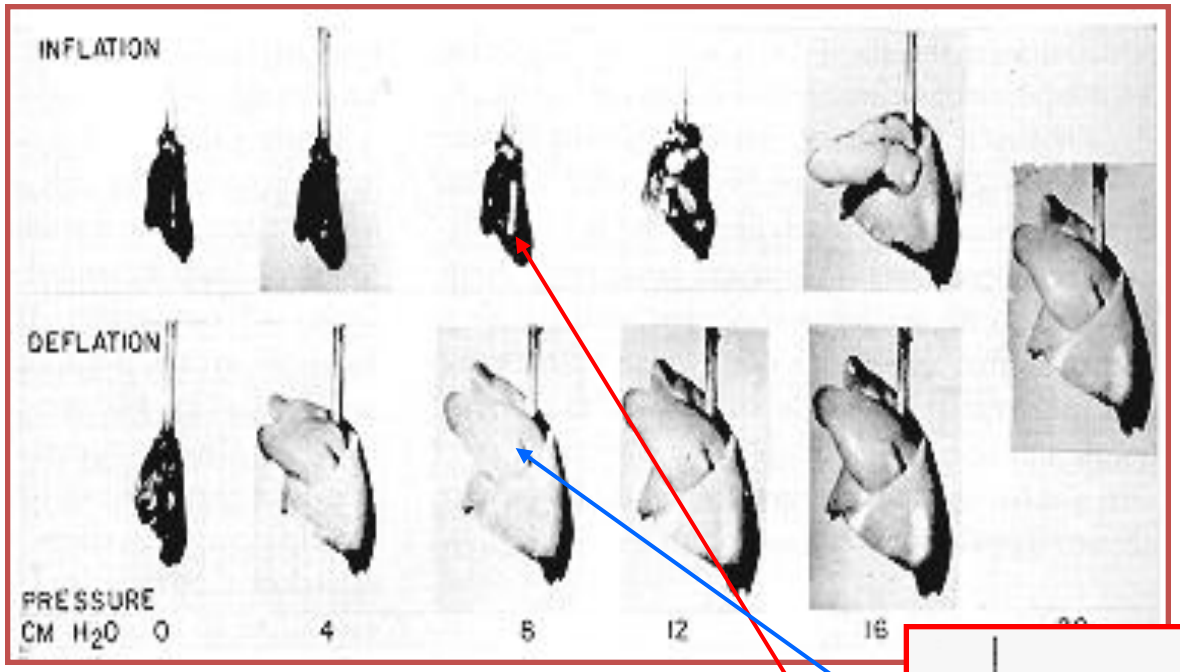
How to optimize lung volume…

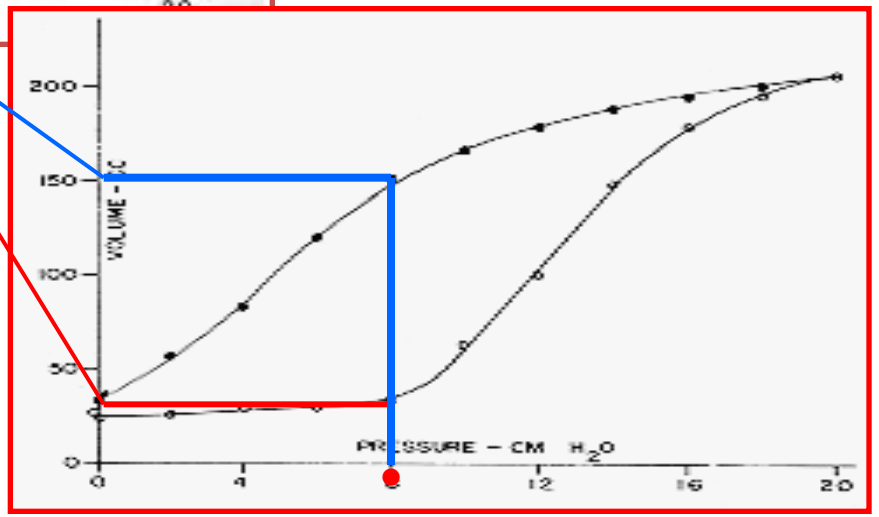


NICU management

(Mechanical ventilation: **which strategy** ?)

Open lung strategy both in HFOV and CMV using «low tidal volume»





75%

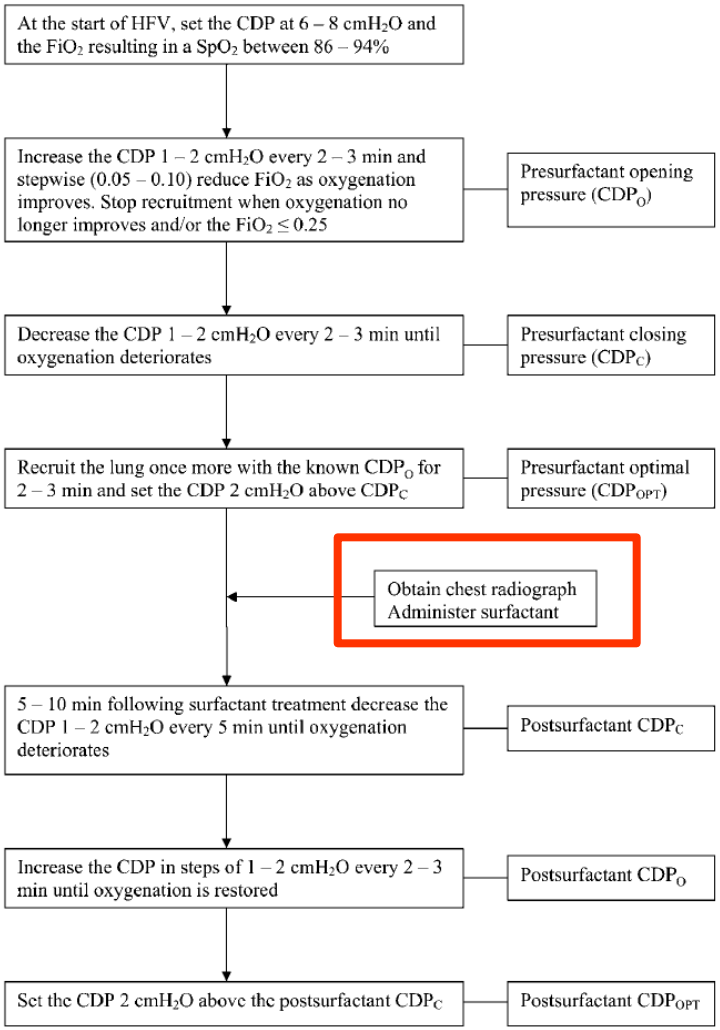
20%

Gentle concession by P.Tagliabue

Lung Recruitment Using Oxygenation during Open Lung High-Frequency Ventilation in Preterm Infants

Anne De Jaegere, Mariëtte B. van Veenendaal, Agnes Michiels, and Anton H. van Kaam

Am J Respir Crit Care Med Vol 174. pp 639–645, 2006



First recruitment maneuver

Figure 1. Pre- and postsurfactant recruitment procedures. CDP = continuous distending pressure; CDP_C = closing pressure; CDP_O = opening pressure; CDP_{OPT} = optimal pressure; F_{IO_2} = fractional inspired oxygen; HFV = high-frequency ventilation; Sp_{O_2} (Stc_{O_2}) = transcutaneous oxygen saturation.

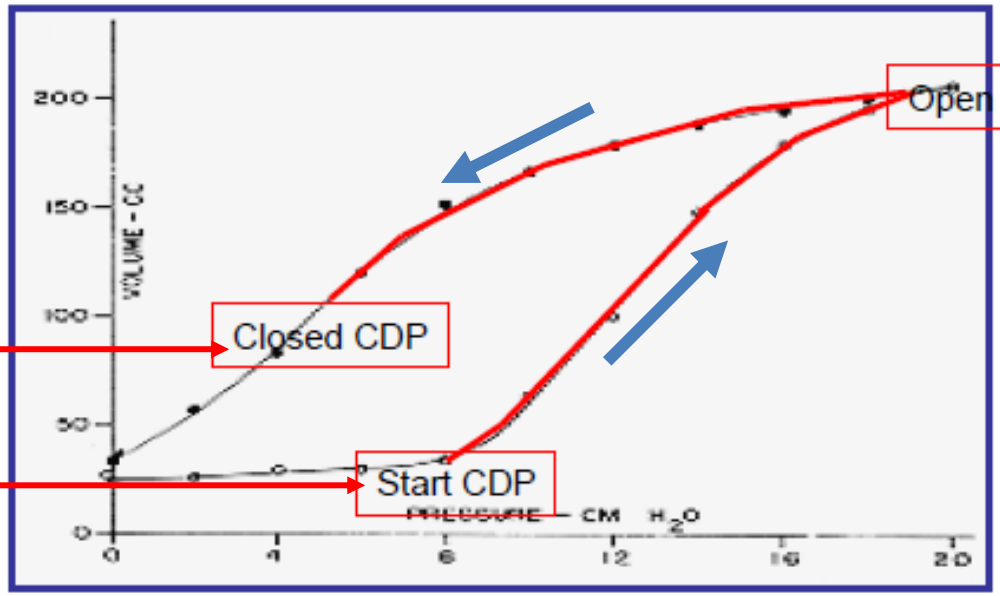
Second recruitment maneuver

Step recruitment on the basis of SpO2 in clinical setting

incremental-decremental CDP trial

CCP= critical closing pressure

COP= critical opening pressure

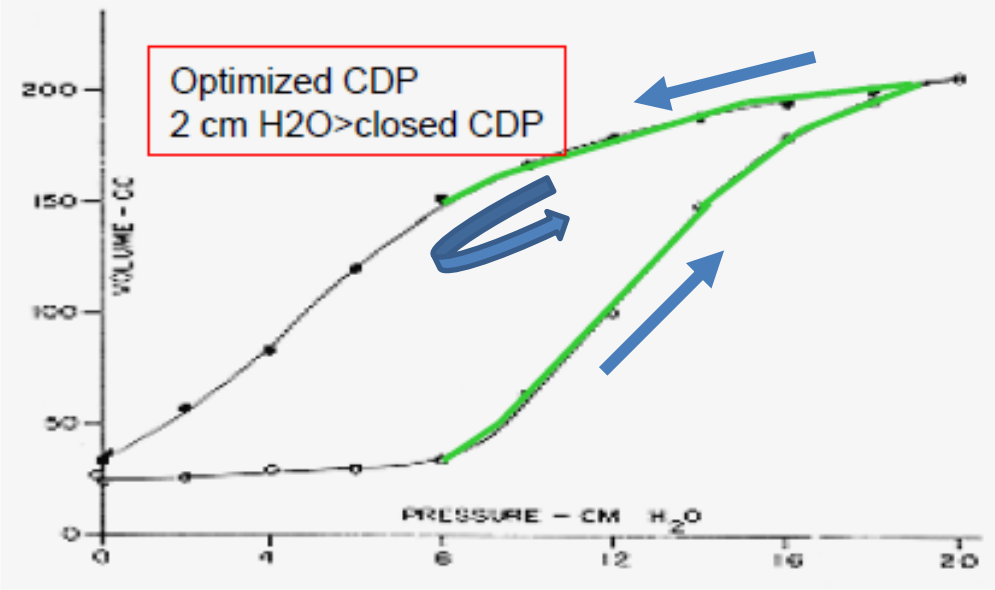


De Jaegere et al
Lung recruitment using oxygenation during open lung high-frequency ventilation in preterm infants.
Am J Respir Crit Care Med. 2006 Sep 15;174(6):639-45. Epub 2006 Jun 8.

Gentle concession by P.Tagliabue

Step recruitment on the basis of SpO2 in clinical setting

decremental CDP trial



Optimized CDP = the lowest possible CDP to maintain an open lung

De Jaegere et al
Lung recruitment using oxygenation during open lung high-frequency ventilation in preterm infants.
Am J Respir Crit Care Med. 2006 Sep 15;174(6):639-45. Epub 2006 Jun 8.

Gentle concession by P.Tagliabue

Mechanical Ventilation of the Neonate: Should We Target Volume or Pressure?

Steven M Donn MD and Win Boon MD

Introduction
Gas Delivery
Limitations of Volume Ventilation
Volume-Targeted Modalities
Hybrid Modalities Providing Volume-Targeted Ventilation
  Volume-Guarantee Ventilation
  Pressure-Regulated Volume Control Ventilation
  Volume-Assured Pressure Support
  Volume-Support Ventilation
  Pressure Augmentation
The Evidence
  Volume-Controlled Ventilation
  Volume-Guarantee Ventilation
  Pressure-Regulated Volume Control
Meta-analysis
Why Does It Work?
Summary

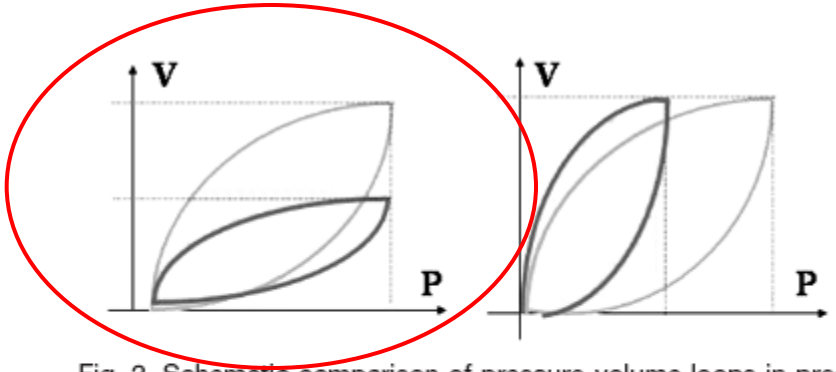


Fig. 3. Schematic comparison of pressure-volume loops in pressure-targeted (left) and volume-targeted (right) ventilation. During pressure-targeting a decrease in pulmonary compliance (moving from light loop to dark loop) results in a loss of tidal volume, despite consistency of inspiratory pressure. During volume-targeting, a decrease in compliance (moving from the dark loop to the light loop) results in an automatic increase in pressure to assure constant volume delivery.

Volume-targeted ventilation

Low risk of hypoventilation

For more than 40 years conventional mechanical ventilation has been used for the treatment of neonatal respiratory failure. Until relatively recently, this was accomplished with time-cycled pressure-limited ventilation, using intermittent mandatory ventilation. Earlier attempts at volume-targeted ventilation were largely ineffective because of technological limitations. The advent of microprocessor-based devices gives the clinician an option to choose either target variable to treat neonatal patients. This paper reviews the principles of each and the accumulated evidence. *Key words: newborn, respiratory failure, mechanical ventilation, pressure-targeted, volume-targeted.* [Respir Care 2009;54(9):1236–1243. © 2009 Daedalus Enterprises]

Steven M Donn MD and Win Boon MD are affiliated with the Division of Neonatal-Perinatal Medicine, Department of Pediatrics, CS Mott Children's Hospital, University of Michigan Health System, Ann Arbor, Michigan.

Dr Donn has disclosed relationships with Discovery Laboratories, Dey, Cardinal Health, and Hamilton Medical. Dr Boon has disclosed no conflicts of interest.

Dr Donn presented a version of this manuscript at the New Horizons Symposium, "Neonatal Respiratory Care," at the International Respiratory Congress of the American Association for Respiratory Care, at the 54th International Respiratory Congress of the American Association for Respiratory Care, held December 13-16, 2008, in Anaheim, California.

Introduction

The traditional method of mechanical ventilation to treat neonatal respiratory failure has been time-cycled pressure-limited ventilation. Originally this was accomplished by modification of adult ventilators. Time-cycled pressure-limited ventilation was easy to use and was felt to safeguard against barotrauma because the peak inspiratory pressure (PIP) could be limited and the ventilator would not exceed this pressure. Unfortunately, the delivered tidal volume (V_T) would fluctuate according to pulmonary compliance; a smaller volume of gas would be delivered at low

Volume targeted vs Pressure limited ventilation in the neonate

Table 1
Major outcomes assessed in the meta-analysis of 11 randomized clinical trials of volume-targeted vs pressure-limited ventilation [15].

Outcome	No. of studies	No. of subjects	RR (95% CI) or mean difference (95% CI)
Mortality	11	767	0.73 (0.51–1.05)
Any IVH	11	759	0.65 (0.42–0.99)[a]
Grade 3–4 IVH	11	707	0.55 (0.39–0.79)[a]
BPD at 36 weeks	9	596	0.61 (0.46–0.82)[a]
Cystic PVL	7	531	0.33 (0.15–0.72)[a]
Pneumothorax	8	595	0.46 (0.25–0.86)[a]
Failure of assigned mode	4	405	0.64 (0.43–0.94)[a]
Any hypocapnia	2	58	0.56 (0.33–0.96)[a]
Duration of supplementary O_2 (d)	2	133	−1.68 (−2.5 to −0.88)[a]

RR, relative risk; CI, confidence interval; IVH, intraventricular hemorrhage; BPD, bronchopulmonary dysplasia; PVL, periventricular leukomalacia.
[a] $p < 0.05$.

Journal of Paediatrics and Child Health

Journal of Paediatrics and Child Health **48** (2012) 740–746

REVIEW ARTICLE

Lung protective ventilation in extremely preterm infants

Peter A Dargaville[1,2] and David G Tingay[3,4,5]

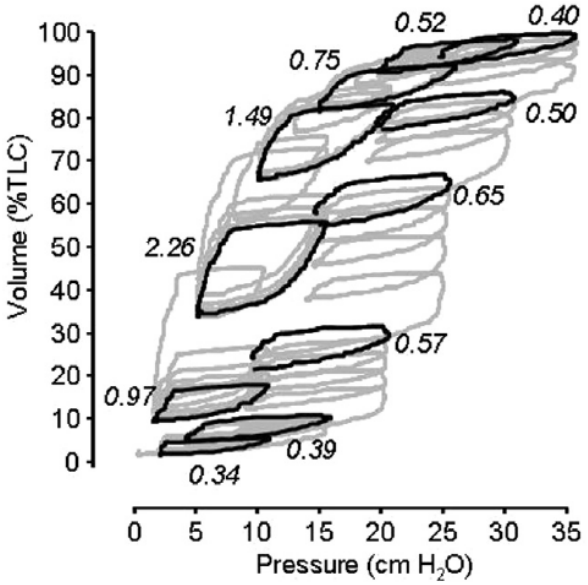


Fig. 1 Stepwise positive end-expiratory pressure (PEEP) manoeuvre during conventional mechanical ventilation (CMV) in a recruitable lung. Pressure–volume tracing during a stepwise PEEP manoeuvre in a mechanically ventilated piglet after repeated saline lavage. PEEP alterations of 5 cm H_2O with a concomitant change in peak inspiratory pressure were made every 15 s. Y-axis shows lung volume measured by respiratory inductance plethysmography, and scaled to total lung capacity (TLC). Complete tracing is shown in grey, and the final breath at each PEEP level in black, and the tidal breath compliance (mL/cm H_2O/kg) for each of the final breaths is indicated in italics. Optimal PEEP as determined by compliance is on the deflation limb at around 5 cm H_2O. Data derived from same experimental series as reference.[23]

Key Points

1 The extremely preterm lung is structurally and biochemically immature and vulnerable to injury from positive pressure ventilation. Implementation of lung protective strategies is vital to minimise the harm caused by mechanical ventilators.

2 Where there is severe respiratory distress syndrome and persistent atelectasis, a lung protective approach composed of recruiting the lung with stepwise pressure increments, followed by reduction of pressure in search of an optimal point at which to maintain ventilation. This form of lung protection is more effectively applied with high-frequency oscillatory ventilation than on a conventional ventilator.

3 Where there is minimal atelectasis, limiting damage to the vulnerable preterm lung involves avoidance of overdistension. This can be achieved by setting positive end-expiratory pressure at the lowest value that maintains oxygenation and restricting tidal volume using a volume-targeted mode of ventilation.

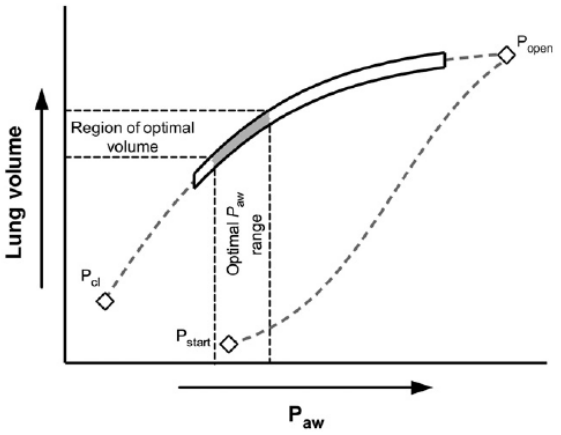


Fig. 2 Lung recruitment and volume optimisation during high-frequency oscillatory ventilation (HFOV). Diagrammatic representation of the pressure–volume (PV) curve in an atelectatic diseased lung. Dashed grey line shows the PV trajectory firstly during escalation of P_{aw} from P_{start} until the lung is maximally recruited (P_{open}) and thereafter with stepwise P_{aw} decrements until oxygenation deteriorates (closing pressure, P_{cl}). Note the hysteresis in PV behaviour with relatively high lung volume maintained on the deflation limb. A broad region of optimal oxygenation is found on the deflation limb (white bar),[46] and a more narrow region in which lung mechanics are optimised (grey fill). HFOV is likely to be most lung-protective if applied in the region of optimal mechanics, usually 2–4 cm H_2O above P_{cl}.

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Paediatric Respiratory Reviews

MINI-SYMPOSIUM: NEONATAL LUNG DISEASE

PEEP – a "cheap" and effective lung protection

Shelley Monkman and Haresh Kirpalani*

Neonatal Intensive Care Unit, Department of Paediatrics, McMaster University Medical Centre, Hamilton, Ontario, Canada

KEYWORDS
PEEP, mechanical ventilation, lung

Summary Mechanical ventilation is a complex therapy with several different parameters which can be altered. In preterm and term infants, more attention has been paid to the levels of peak inspiratory pressure than to the positive end-expiratory pressure (PEEP). An awareness that lung protection can be conferred by an appropriate level of PEEP has increasingly stimulated a renewed interest in achieving the "best PEEP" strategy. We review the history of the introduction of PEEP therapy, some of the early demonstrations of its potential for mischief, the evidence on what levels of PEEP are appropriate in infants, some data concerning the lung-protective value of PEEP and finally some recent efforts at defining measures to determine the so-called "best PEEP". Some of this work has been performed in adults with the acute respiratory distress syndrome. In newborns, we are regrettably forced to conclude that there is, for the immediate present, no easy substitute for sensible clinical observations coupled with a judicious and cautious adjustment of PEEP. We anticipate that a more logical application of PEEP with individualisation of therapy, based on a pressure–volume relationship, will in future enable targeted tests of PEEP as a lung-protection strategy.
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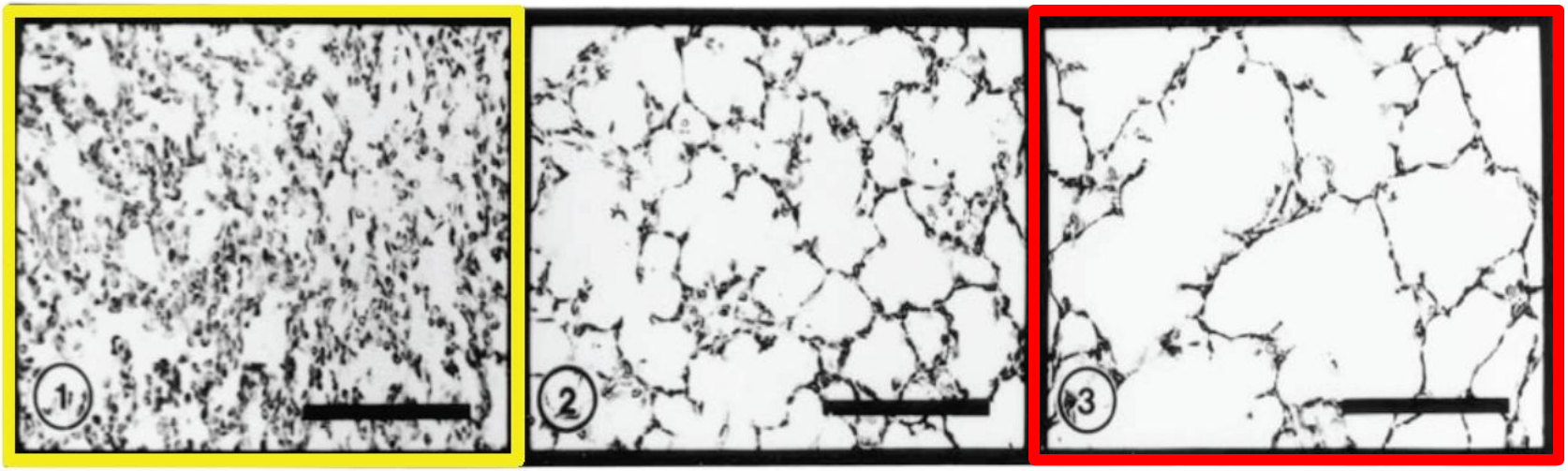
PRACTICE POINTS

- ZEEP is deleterious even in diseases such as meconium aspiration with apparent areas of overinflation. This is often accompanied by areas of collapse or underdistension, for which the presence of even a small degree of PEEP could be useful. In hyaline membrane disease, the nature of the lack of homogeneity is even more obvious making ZEEP a contraindication.
- When changing ventilator settings ensure that each step is accompanied by an adequate time interval to enable the effects of the changes to be detectable at steady state. Attention should be paid to oxygen saturation, and the evidence of adequate peripheral perfusion and central blood pressure. A blood gas level should be obtained to verify the observed non-invasive trends of oxygen saturation and/or transcutaneous carbon dioxide monitoring.
- A chest X-ray may be helpful. There may be areas of regional collapse or underdistension that might benefit from a higher level of PEEP.

Note whether the heart is "squeezed" or compressed, suggesting a need to volume-prime to increase the preload or to make a slight reduction in the degree of PEEP applied. The future is likely to reveal some more logical means by which to titrate levels of PEEP.

The role of “adequate”PEEP

A



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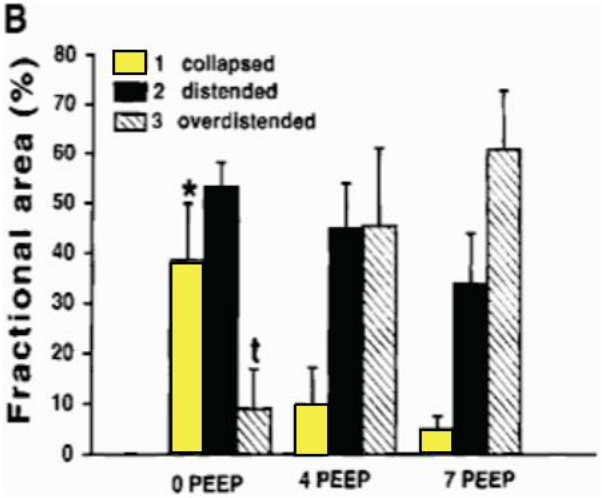
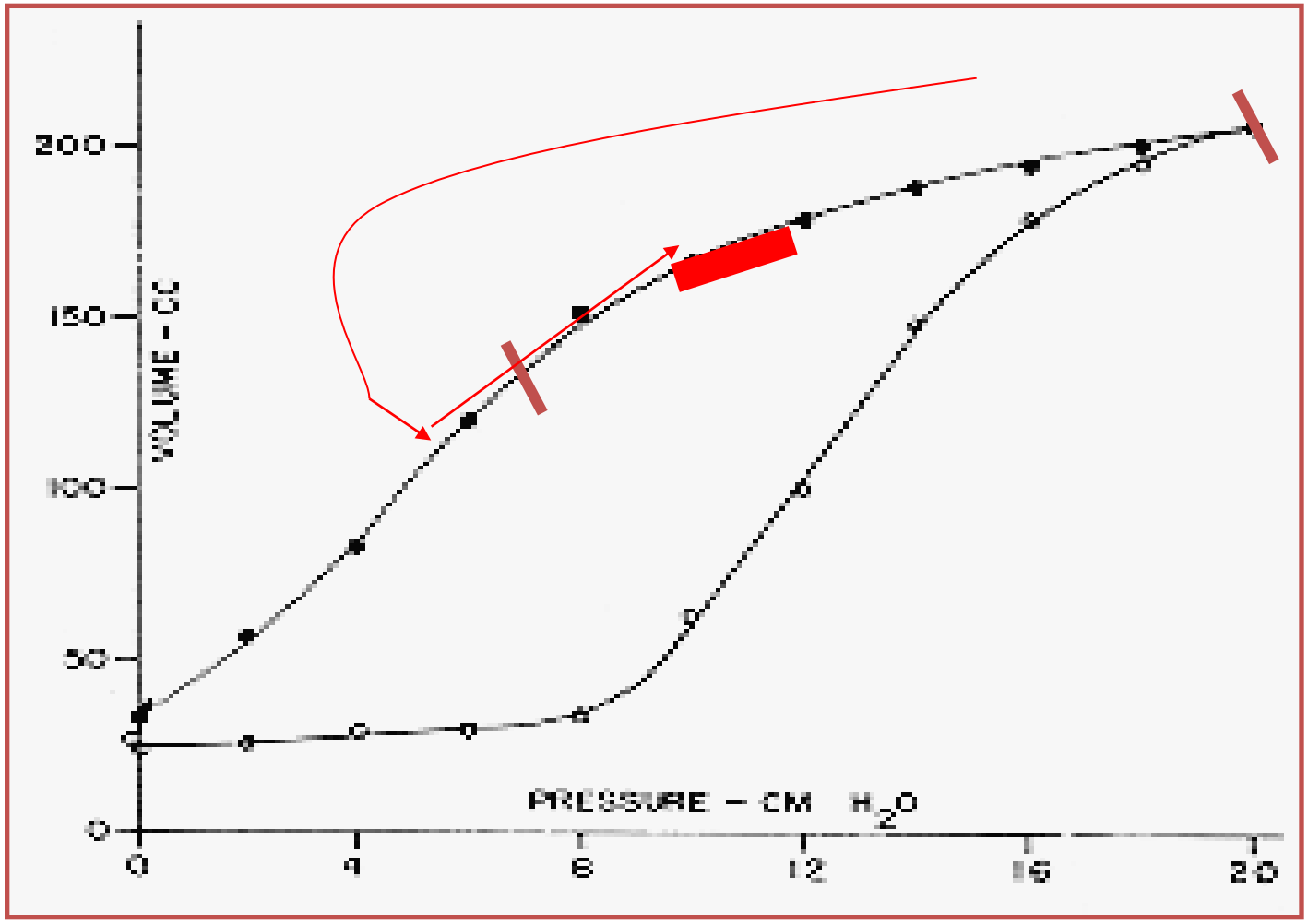


✓ The percentage fractional area of ***collapsed*** alveoli in preterm lambs is significantly higher for 0 PEEP

NaiK AS ;Am J Respir Crit Care Med 2001

How to search the optimal PEEP ?

Lung recruitment: optimal PEEP to reach lung volume on the deflation limb of P/V curve



"Lung volume optimization for VLBWi in VG ventilation "

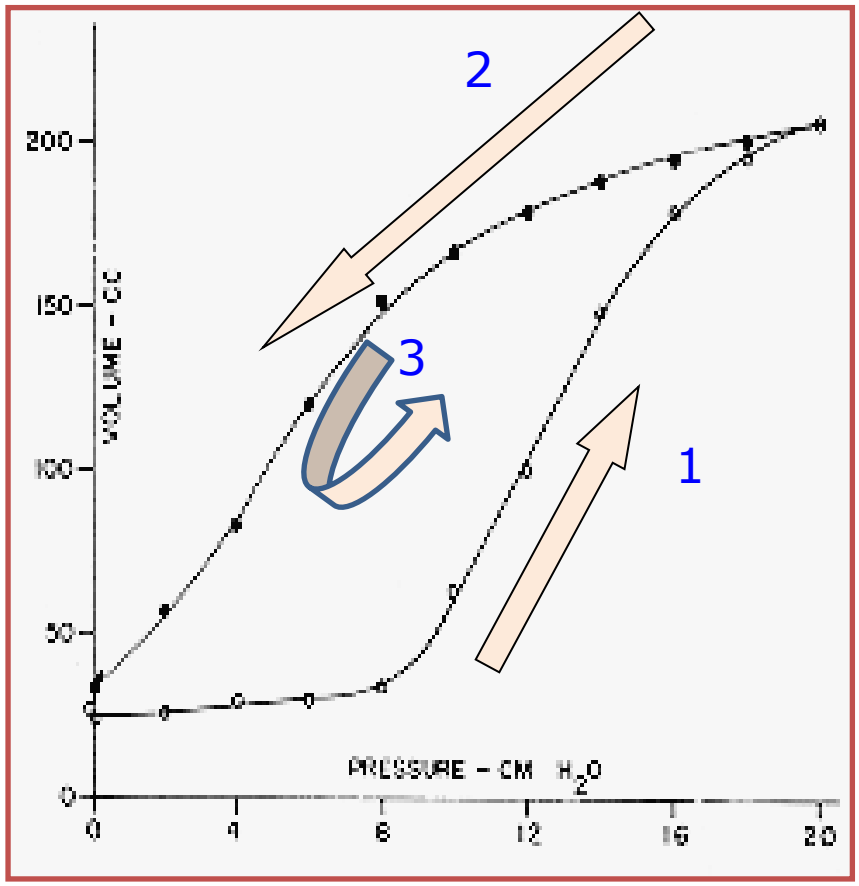
SLI manouvre in DR; in mechanically ventilated (AC plus VG: Vt 6ml/kg; Draeger VN 500; initial PEEP = 5 cmH_2O) with persistent high request of FiO2 and PIP level; surfactant; monitor $TcpO_2$ /$TcpCO_2$, SpO_2,BP, HR

- Increments of PEEP (0.2 cmH_2O every 5') monitoring the falling FiO2 needs and rising SpO2 (1)

- When FiO2 needs fell to 0.3, PEEP is reduced in order to set the lung filling on the safe deflation limb of P/V curve above the critical closing pressure (CCP) (2).

- When oxygenation levels falls and FiO2 rises, we re-increment PEEP until stable oxygenation is achieved (3).

- In case of initial need of FiO2< 0.3 we try to reduce PEEP level according to SpO2 target and FiO2 request (then we try to reduce Vt)



Lung Recruitment Maneuver during Volume Guarantee Ventilation of Preterm Infants with Acute Respiratory Distress Syndrome

Francesca Castoldi, M.D.,[1] Irene Daniele, M.D.,[1] Paola Fontana, M.D.,[1] Francesco Cavigioli, M.D.,[1] Enrica Lupo, M.D.,[1] and Gianluca Lista, M.D.[1]

AMERICAN JOURNAL OF PERINATOLOGY **2011,**

Table 1 Ventilatory and Gas Analysis Changes During the LRM and in the First 12 Hours of Life

	Group A ($n=10$)	Group B ($n=10$)	p	
Fio_2 at start of LRM (%)	56 ± 24	52 ± 21	0.7	
Lowest Fio_2* (%)	22 ± 2†	24 ± 2†	0.08	⇦
Time to lowest Fio_2 (min)	94 ± 24	435 ± 221	0.0009	⇦
PEEP at start of LRM (cm H_2O)	5 ± 0.2	5 ± 0.2	0.4	
Max PEEP during LRM (cm H_2O)	6.1 ± 0.3†	5.3 ± 0.3	0.00	⇦
Final PEEP at the end of LRM (cm H_2O)	5 ± 0.3	5.1 ± 0. 3	0.2	
a/Ao_2 ratio at start of LRM	0. 25 ± 0.1	0.25 ± 0.1	0.9	
a/Ao_2 ratio final*	0.47 ± 0.1†	0.34 ± 0.1	0.03	⇦
Pao_2 at start of LRM (mm Hg)	59 ± 12	64 ± 11	0.3	
Pao_2 final* (mm Hg)	79 ± 20†	66 ± 12	0.08	⇦

*In the first 12 h of life.
†$p < 0.05$ versus at start of LRM.
a/Ao_2. Fio_2, Q10fraction of inspired oxygen; LRM, lung recruitment maneuver; Pao_2; Q11PEEP, positive end-expiratory pressure.

(Group A) n= 10 ; mean GA 25 ± 2 wks ; BW 747 ± 233 g
(Group B) n=10 ; mean GA 25 ± 2 wks ; BW 737 ± 219 g

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AMERICAN JOURNAL OF PERINATOLOGY **2011**

Table 2 Respiratory and Clinical Outcomes

	Group A ($n=10$)	Group B ($n=10$)	p
Surfactant doses (n)	1.2 ± 0.4	1.8 ± 0.8	0.09
Extubation failure (n)	1	1	NS
Length of respiratory support (d)	24 ± 13	35 ± 17	0.19
Length of tracheal intubation (d)	8.7 ± 7	18.9 ± 15	0.07
PDA occurrence (n)	6/10	4/10	0.61
Maternal chorioamnionitis (n)	4/10	3/10	0.99
Sepsis (n)	4/10	4/10	NS
O_2 dependency (d)	29 ± 12	45 ± 17	0.04 ⇦
Moderate or severe BPD (n)	0	2 (20%)	0.4
ROP grade >2 (n)	3 (30%)	6 (60%)	0.3
Death (n)	2 (20%)	2 (20%)	NS

BPD, bronchopulmonary dysplasia; NS, not significant; PDA, patent ductus arteriosus; ROP, retinopathy of prematurity.

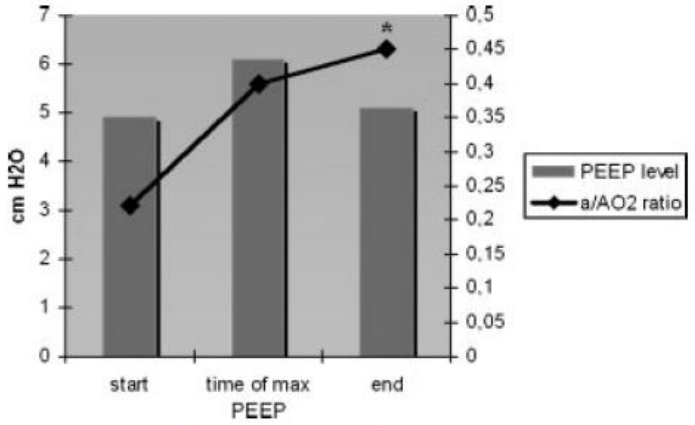


Figure 1 Fraction of inspired oxygen requirements of infants in group A ($n = 10$) in the course of lung recruitment maneuver (data expressed as mean values). *$p < 0.05$ versus start level. PEEP, positive end-expiratory pressure; a/Ao_2[Q12].

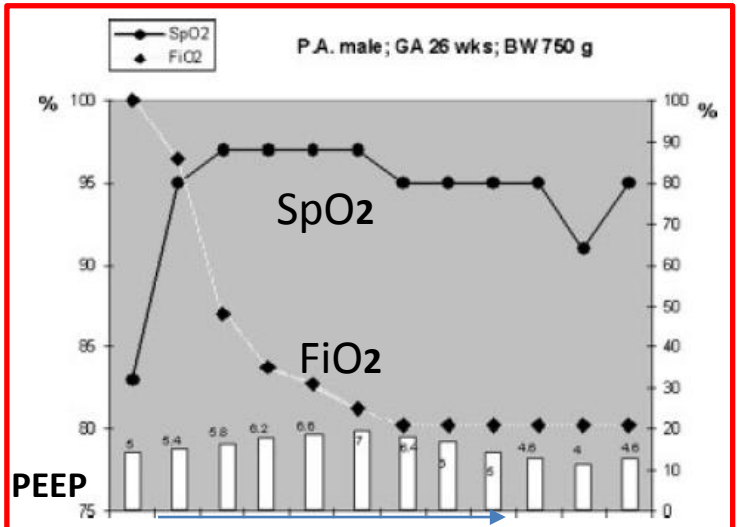


Figure 3 Spo_2[Q14] and fraction of inspired oxygen (Fio_2) changes over time during lung recruitment maneuver in one preterm infant in group A. Positive end-expiratory pres-

PEEP TRIAL= 2nd recruitment maneuver

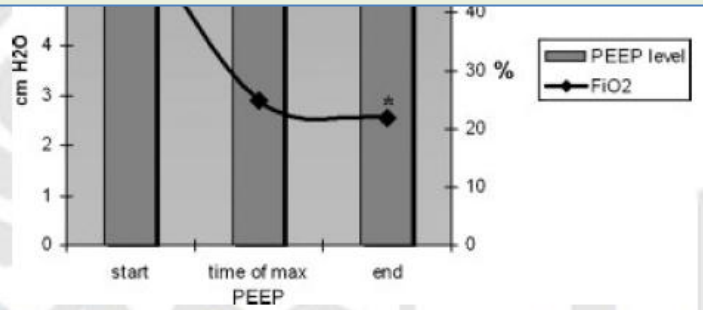


Figure 2 a/Ao_2[Q13] ratio of infants in group A ($n = 10$) in the course of lung recruitment maneuver (data expressed as mean values). *$p < 0.05$ versus start level. Fio_2, fraction of inspired oxygen; PEEP, positive end-expiratory pressure.

group was observed. No differences were observed in extubation failure, BPD, ROP, and death between the two groups. During the LRM application, no adverse events occurred, circulatory parameters were stable, and the maneuver was well tolerated. All results are presented as mean ± standard deviation or rate and percentage. In Fig. 3, step-by-step changes in Spo_2 and Fio_2 related to PEEP levels during the LRM application to a male preterm infant of group A are shown. PEEP changes are shown (in white bars) on the abscissa axis as they were progressively applied during maneuver

WARNING

"Lung Recruitment for Ventilation: does it work? Is it safe?"
Jobe A. J
Pediatrics 2009; 154: 635-636

- demanding and time consuming assessments are requested
- PAWs used to define the open lung are high
- Risk of air leaks
- Lung stretch may transduce inflammatory signals
- Haemodynamic effect

Cardiorespiratory effects of changes in end expiratory pressure in ventilated newborns

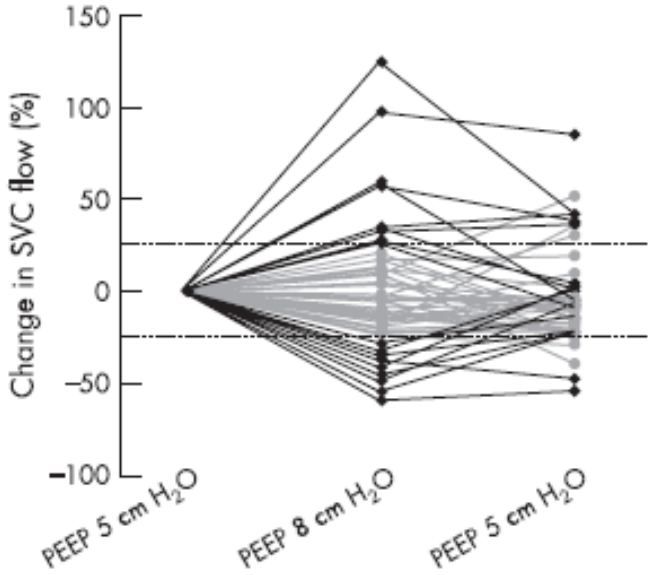
Koert A de Waal, Nick Evans, David A Osborn, Martin Kluckow

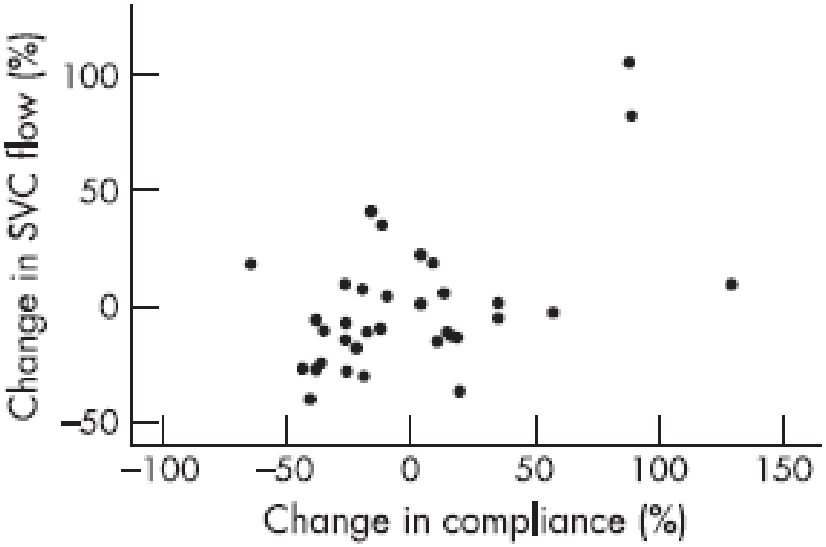
Table 1 Cardiovascular response to an increase in positive end expiratory pressure (PEEP) in all 50 infants*

	Baseline PEEP 5 cmH_2O	Intervention PEEP 8 cmH_2O	Return to PEEP 5 cmH_2O	p Value
Right ventricular output (ml/kg/min)	234 (103)	218 (95)	224 (87)	0.014
SVC (ml/kg/min)	92 (36)	87 (36)	86 (34)	0.207
SVC diameter (mm)	3.7 (1.0)	3.6 (1.1)	3.6 (1.0)	0.040
SVC velocity time integral (m/s)	0.093 (0.032)	0.097 (0.035)	0.090 (0.029)	0.172
Left pulmonary artery velocity (m/s)	0.33 (0.11)	0.32 (0.13)	0.32 (0.12)	0.669
Duct diameter (mm)	2.2 (1.6–3.0)	2.2 (1.9–28)	2.1 (1.8–3.1)	0.628
Ductal shunt (%RL)	14 (0–25)	12 (0–27)	15 (0–28)	0.760
Middle cerebral artery mean (m/s)	0.13 (0.09–0.17)	0.14 (0.10–0.18)	0.12 (0.09–0.16)	0.190
Heart rate (beats/min)	143 (17)	141 (20)	143 (19)	0.198
Systolic blood pressure (mm Hg)	47 (9)	48 (9)	47 (9)	0.265
Diastolic blood pressure (mm Hg)	30 (7)	30 (6)	30 (6)	0.602

%RL, percentage of cardiac cycle with right to left shunt; SVC, superior vena cava flow; Vti, velocity time integral.
*Values expressed as mean (SD) or median (IQR) where appropriate.

Arch Dis Child Fetal Neonatal Ed 2007;**92**:F444–F448





Conclusion: A short-term increase in PEEP does not lead to significant changes in systemic blood flow, although 36% of infants in the present study had clinically important changes in flow (±25%). The intervention can improve dynamic lung function, especially airway resistance. Improvements in compliance tend to be associated with improvements in blood flow.

Arch Dis Child Fetal Neonatal Ed 2007;92:F444–F448

Pediatric Anesthesia

Pediatric Anesthesia 2009 **19**: 1207–1212 doi:10.1111/j.1460-9592.2009.03177.x

Alveolar recruitment strategy and PEEP improve oxygenation, dynamic compliance of respiratory system and end-expiratory lung volume in pediatric patients undergoing cardiac surgery for congenital heart disease

THIERRY V. SCOHY MD*, IDO G. BIKKER MD*, JAN HOFLAND MD PhD*, PETER L. DE JONG MD†, AD J.J.C. BOGERS MD PhD† AND DIEDERIK GOMMERS MD PhD*‡

**Department of Anaesthesiology, Erasmus Medical Center, Rotterdam, †Department of Cardiothoracic Surgery, Erasmus Medical Center, Rotterdam and ‡Department of Intensive Care, Erasmus Medical Center, Rotterdam, The Netherlands*

Summary

Objective: Optimizing alveolar recruitment by alveolar recruitment strategy (ARS) and maintaining lung volume with adequate positive end-expiratory pressure (PEEP) allow preventing ventilator-induced lung injury (VILI). Knowing that PEEP has its most beneficial effects when dynamic compliance of respiratory system (Crs) is maximized, we hypothesize that the use of 8 cm H_2O PEEP with ARS results in an increase in Crs and end-expiratory lung volume (EELV) compared to 8 cm H_2O PEEP without ARS and to zero PEEP in pediatric patients undergoing cardiac surgery for congenital heart disease.

Methods: Twenty consecutive children were studied. Three different ventilation strategies were applied to each patient in the following order: 0 cm H_2O PEEP, 8 cm H_2O PEEP without an ARS, and 8 cm H_2O PEEP with a standardized ARS. At the end of each ventilation strategy, Crs, EELV, and arterial blood gases were measured.

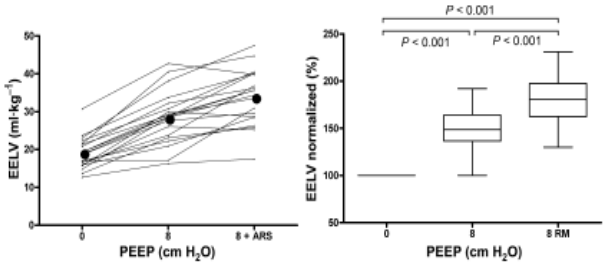
Results: EELV, Crs, and P_aO_2/FiO_2 ratio changed significantly ($P < 0.001$) with the application of 8 cm H2O + ARS. Mean P_aCO_2 – $PETCO_2$ difference between 0 PEEP and 8 cm H2O PEEP + ARS was also significant ($P < 0.05$).

Conclusion: An alveolar recruitment strategy with relative high PEEP significantly improves Crs, oxygenation, P_aCO_2 – $PETCO_2$ difference, and EELV in pediatric patients undergoing cardiac surgery for congenital heart disease.

Keywords: alveolar recruitment; dynamic compliance; pediatric; positive end-expiratory pressure

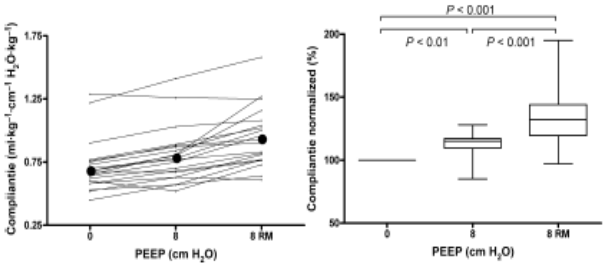
Table 1
Patient demographics

N	*20*
Gender, female/male	6/14
Age, months (median + range)	34 (3–132)
Weight, kg (median + range)	10.1 (8.8–15.5)
Length, m (median + range)	0.85 (0.75–1.07)



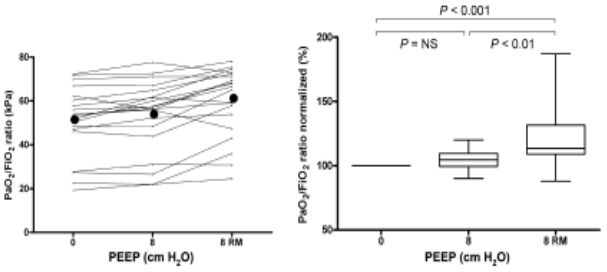
EELV

Figure 1
End-expiratory lung volume(EELV) per kg vs positive end-expiratory pressure (PEEP).



Crs

Figure 2
Crs vs positive end-expiratory pressure (PEEP).



PaO_2/FiO_2

Figure 3
P_aO_2/F_iO_2 ratio vs positive end-expiratory pressure (PEEP).

"*Research of optimal PEEP*" = not only SpO2 monitoring

Electrical Impedance Tomography

Dräger

HOW EIT WORKS

It is well-known that the bioelectric properties of lung tissue are affected by the air content. Consequently, changes in lung volume due to ventilation result in changes of the thoracic impedance.

To monitor thoracic impedance changes, electrodes have to be placed around the patient's chest wall, tiny electrical currents are applied to the body through one electrode pair and the resulting voltages are measured simultaneously at other electrode pairs (Fig. 1).

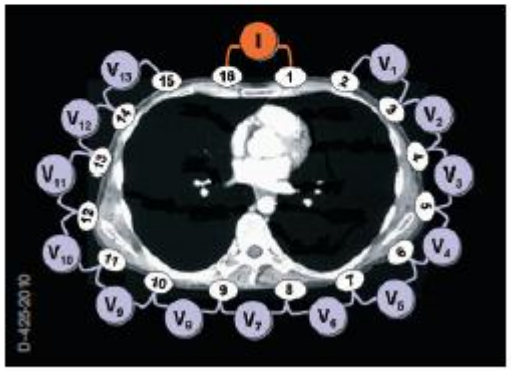


Fig. 1: A first pair of electrodes applies a very small current into the thorax while the remaining 13 electrode pairs measure the resulting voltage signals and their changes.

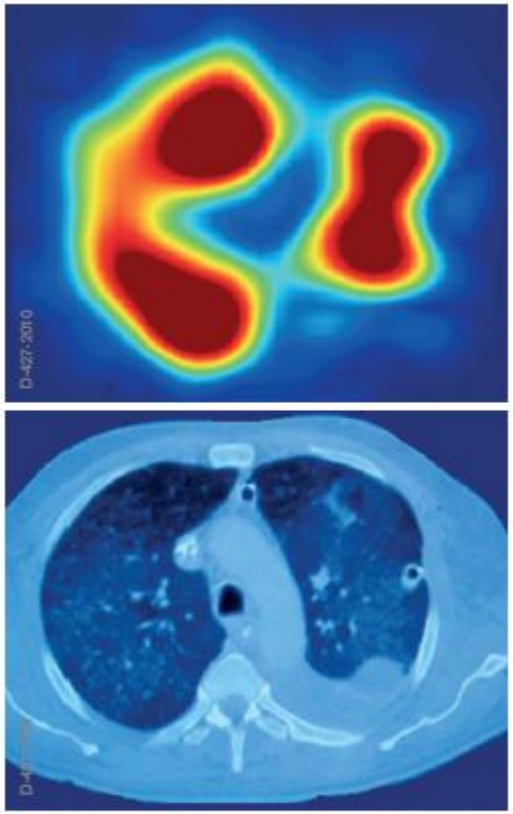
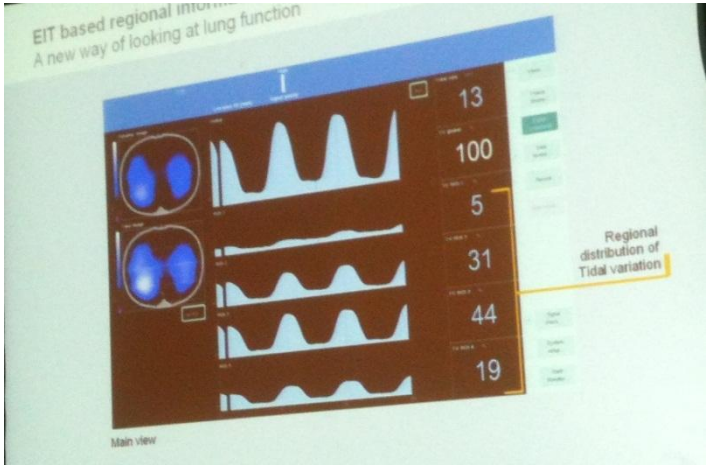
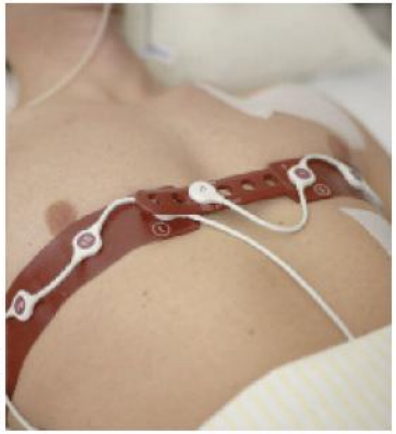


Fig. 4: Functional EIT image (left) and CT scan from a patient with a pleural effusion after rupture of the diaphragm, resulting in a significantly reduced ventilation of the lower left lung. The red color represents regions with the highest volume changes, the non-ventilated regions are displayed in deep blue.



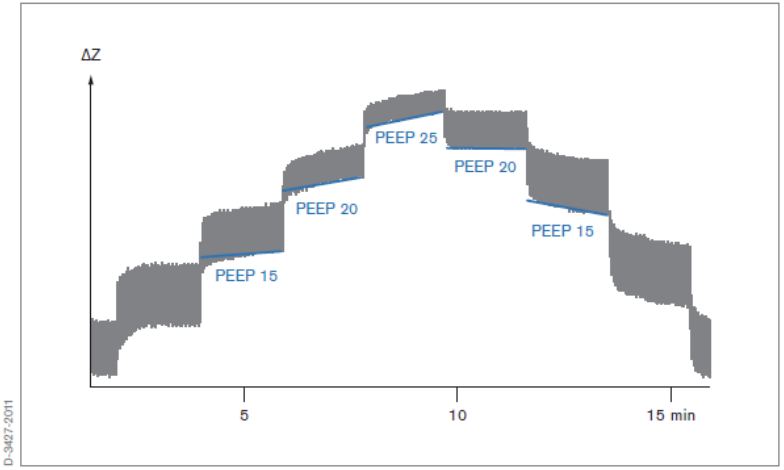
D-101-2010

Fig. 9: PulmoVista 500



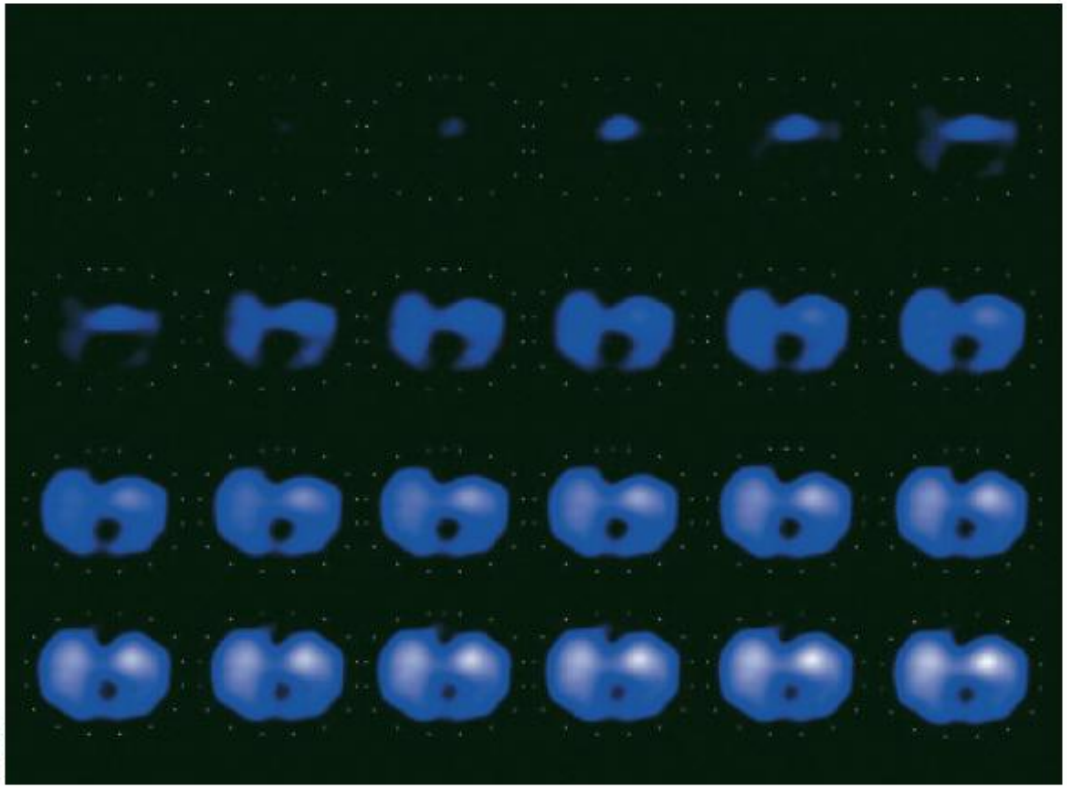
D-28332-2009

Fig. 10: Electrode belt with patient cable connected



D-3427-2011

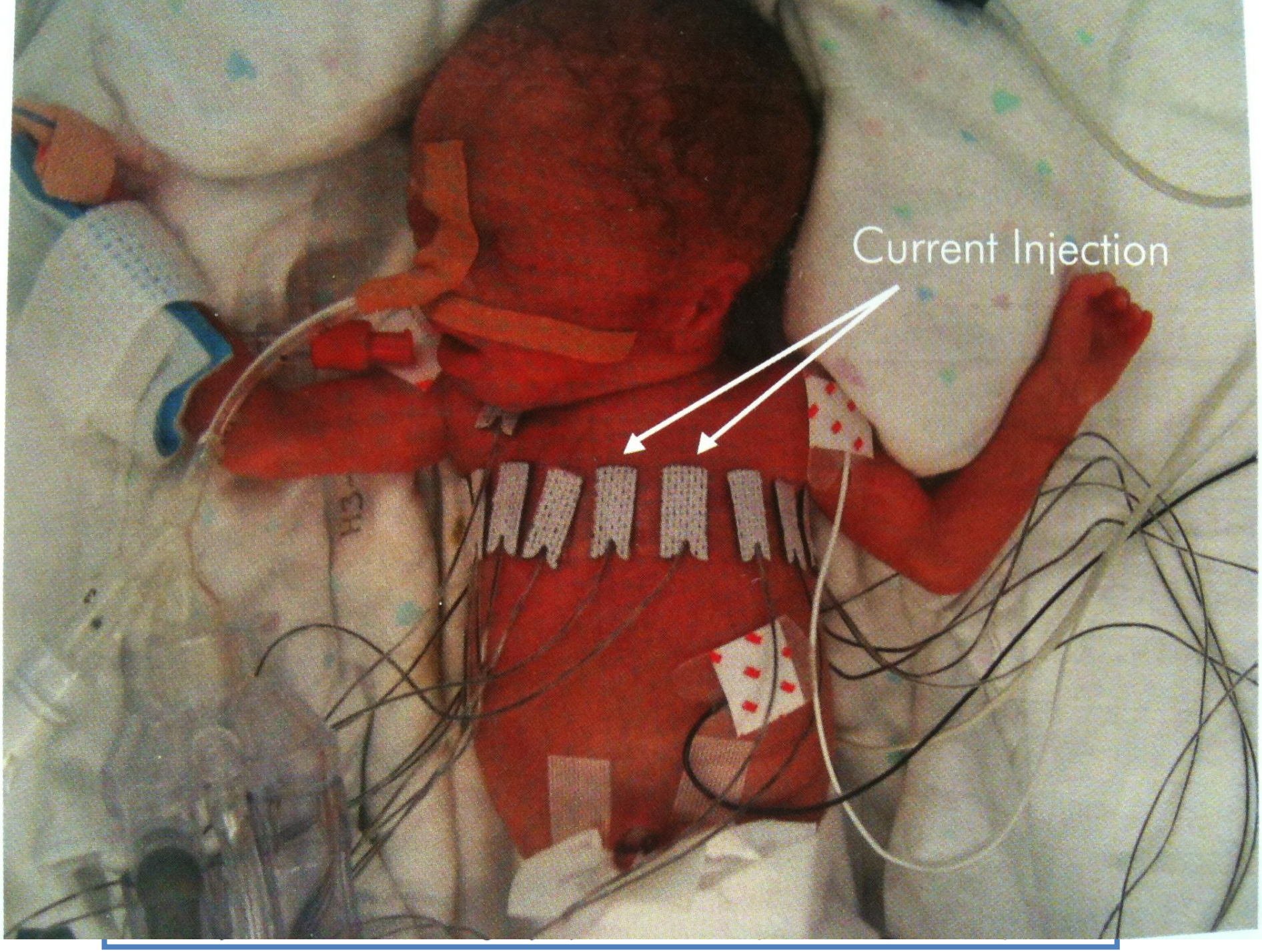
Fig. 36: Defining optimal PEEP settings based on the assessment of ΔEELI



D-46-2011

Fig. 24: Series of dynamic images representing air filling during inspiration

Dräger


Current Injection

Measurements of respiratory volumes in mechanically ventilated by utilizing the **opto-electronic plethysmography (OEP**), a noninvasive method to study the volume and motion of the human trunk through the use of infrared imaging.
(OEP system, BTS, Milano, Italy).

Aliverti A et al. Am J Crit Care Med 2000;161:1546-1552

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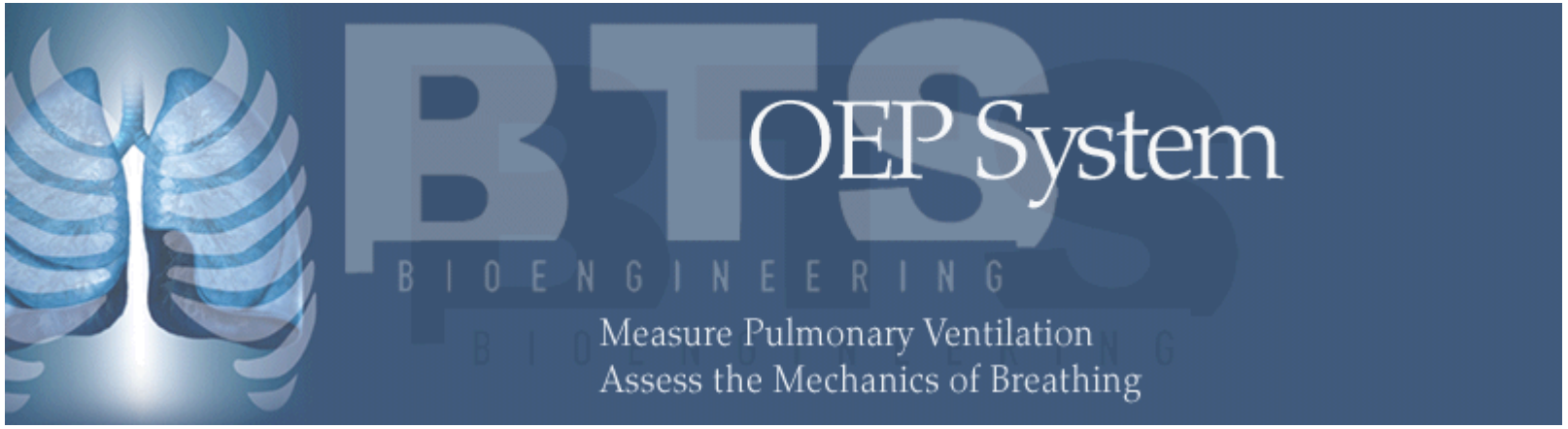
Dellacà RL et al. PLoS One 2015;10(3):e0116317. doi: 10.1371

Lista G et al. , Respiratory Medicine Case report 2017

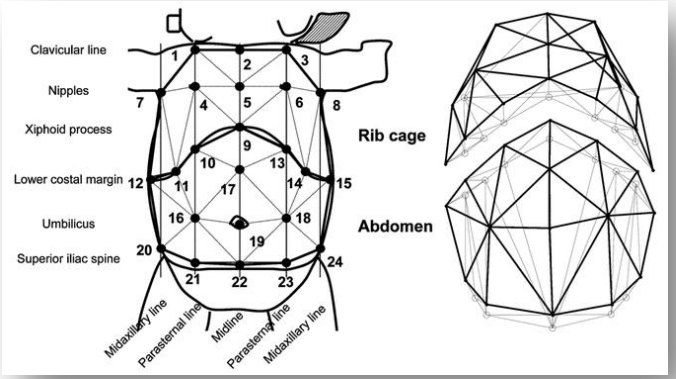


Optoelectronic Plethysmography is a new method to evaluate ventilation through an external measurement of the chest wall surface motion.

A number of small reflective markers are placed on the thoraco-abdominal surface by hypoallergenic adhesive tape.

A set of specially designed video cameras analyze the chest wall motion (infrared imaging).

A dedicated software computes the enclosed volume and its variations during breathing.



Respiratory Medicine Case Reports 22 (2017) 133–136

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journal homepage: www.elsevier.com/locate/rmcr

Case report

Efficacy of lung volume optimization maneuver monitored by optoelectronic pletismography in the management of congenital diaphragmatic hernia

G. Lista [a,*], I. Bresesti [a], F. Cavigioli [a], F. Castoldi [a], E. Lupo [a], A. LoMauro [b], A. Aliverti [b]

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[b] Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Milan, Italy

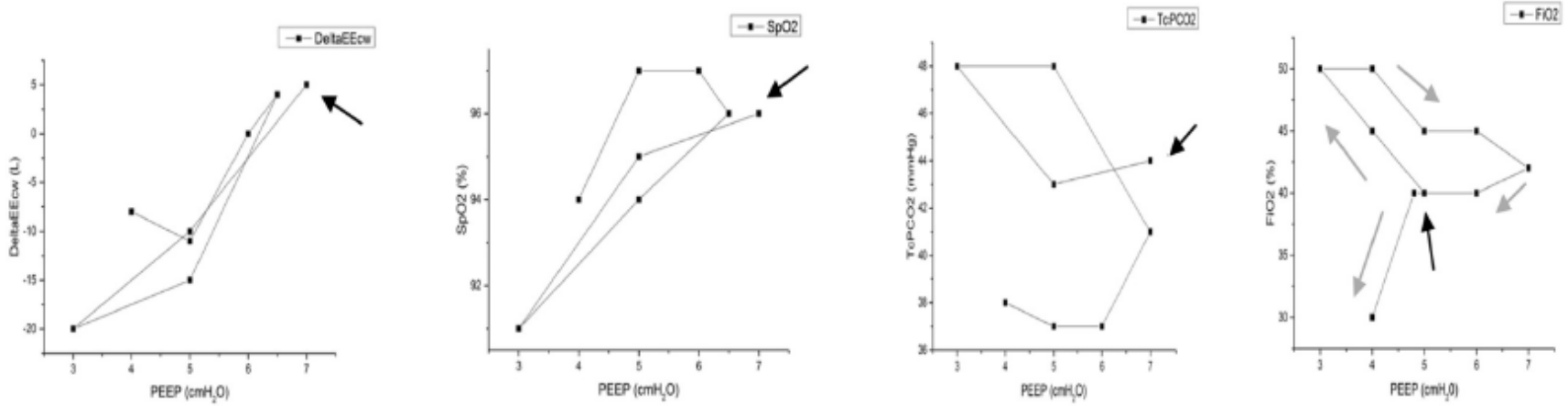

Fig. 2. End-expiratory chest wall volume variation (ΔEEcw), pulse oxygen saturation (SpO_2), *trans*-cutaneous partial pressure of carbon dioxide ($TcPCO_2$) and fraction of inspired oxygen (FiO_2) during high lung volume strategy after surgery in CMV. Driving pressure is positive end-expiratory pressure (PEEP) and it is reported on the x-axis. The black arrow indicates the starting point and the grey ones clarify the direction of the maneuver.

Lung Volume Optimization in course of MV….and prevention of lung injury

- to know the physiology and to allow fetal-neonatal transition of the lung
- to set a «lung volume optimization strategy» from the DR (e.g.SI + CPAP or stepwise increments of PEEP) to obtain an early FRC
- in CMV : to choice a «targeted-volume ventilation» (first intention) plus the research of the optimal «PEEP»
- appropriate timing for surfactant administration (early!!) and modality (under investigation)
- in HFOV : to choice an «high lung volume strategy» (better as first intention)
- to use clinical monitoring for the lung volume optimization (SpO_2/$TCpCO_2$/pO_2, BP and HR)
- It is desirable in the future a «bedsite patient control of regional distribution of volume» (by EIT) or a method to evaluate ventilation through an external measurement of the chest wall surface motion (= volume variations of entire chest wall) (by OEP).