Mechanical Ventilation in the OR: Current Evidence and Recommendations

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Disclosures

- I, nor my spouse, have any financial obligations to this lecture to disclose.
- Any medical equipment shown in this lecture are simply to provide examples and not to promote any specific company or product.

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Objectives

1. Review modes of ventilation utilized in the operating room, briefly
2. Review history of lung protective ventilation and how it became to be utilized in the OR
3. Discuss use of lung protective ventilation in the operating room to prevent post-operative pulmonary complications
4. Discuss driving pressure, and its increasing evidence as a marker for pulmonary damage

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Modes of Ventilation

- Most commonly used modes in OR include volume control and pressure control
- Machines are becoming more sophisticated
- Have modes available that weren't common except in the ICU setting
- Many machines have settings for Bi-Vent, Pressure Support

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Pro/Con of Volume vs. Pressure Control

- Many times, which is used is determined by provider preference

Volume Control	Pressure Control
Advantages: precise tidal volume control, more accurate minute ventilation	Advantages: maintain low airway pressure when desired, control peak pressures
Disadvantages: volutrauma,barotrauma variable pressure, leaks result in volume loss	Disadvantages: variable volumes delivered, barotrauma and volutrauma if settings too high

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Other Options

- Pressure Regulated Volume Control (PRVC)
  - A little of both worlds
  - Ventilator uses previous pressure requirements to deliver tidal volumes
  - Can set limits for alarms-avoid barotrauma
- Synchronized Intermittent Mandatory Ventilation (SIMV)
  - Allows patient triggered breaths
  - Gives breath if patient does not initiate
- Pressure Support
  - Per definition of the ASA, requires spontaneous ventilation

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Why can MV be bad?

- Un-natural method of breathing
  - Lose the natural movement of diaphragm, elastic recoil of lungs and chest wall
- Air flow into lungs is heterogenous
- Collapse of airways occurs in nearly 100% of patients undergoing GA
- Expose alveoli to excessive shear stress
  - Typically with excessive volume, pressure, or both
- Can cause short term and long term problems

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Effects of Anesthesia

- Decrease in functional residual capacity
  - Decrease in muscle tone
  - Decrease in lung compliance
  - Increased closing capacity
- Type of surgery can increase atelectasis
  - Thoracic and cardiac highest rates
  - Abdominal surgery
- Everyone develops atelectasis!
- Supine position augments airflow during mechanical ventilation
  - Non-dependent areas preferentially ventilated

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Atelectasis

Magnusson and Spahn

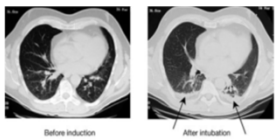

Fig 1 Examples of CT scans of a patient with healthy lungs, before and after induction of anaesthesia. The CT slices are 1 cm above the level of the right diaphragm. Arrows indicate lung densities, thought to represent atelectasis (from Rusca and colleagues[36]).

Magnusson L, Spahn DR. *"New Concepts of Atelectasis During Anesthesia".* Br J Anaesth 2003; 91: 61-72

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Mechanical Injury of Airway Units

- Can be caused by either excess volume or pressure
- Both lead to damage at the cellular level
  - Causes release of inflammatory mediators
  - Increased macrophage activity
  - Capillary leak
- What's better? Volume (prevent atelectasis) vs PEEP (risk overdistention)
- Volutrauma shown to directly activate monocytes in the pulmonary system causing systemic cytokine release
  - PEEP shown to have protective effect as it preserved cell-cell and cell-matrix junctions in the lung

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Non-Protective Ventilation

- Typically tidal volumes of > 8 ml/kg PBW
  - Typically 10-15 ml/kg PBW in review of the literature
- Zero PEEP
- High TV can lead to high peak and plateau pressures
- Shown in healthy patients to cause increase in inflammatory markers
- Ventilator induced lung injury can be induced with this strategy
  - High TV causes overdistention of aerated lung (volutrauma)
  - No PEEP allows airway collapse, leads to atelectasis. Can then perpetuate with repeated opening and closing during MV (atelectrauma)
  - High airway pressure can cause barotrauma

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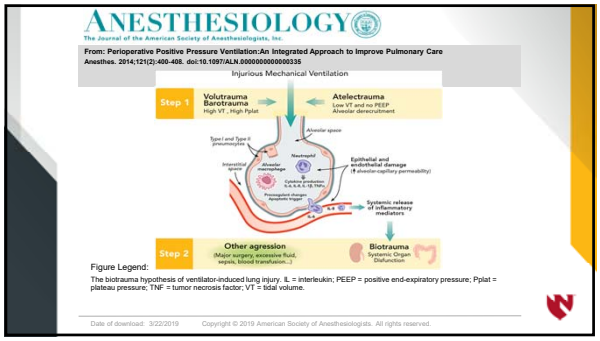

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Other Effects of Atelectasis

- Reduces surfactant production
- Increases shunt, leads to hypoxia potentially
  - Increased FiO2 may worsen atelectasis due to resorption behind closed airways
- Nidus for development of infection
- Possible cause for non-invasive or invasive ventilation

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So What????

- Is it really a big deal?
- My patient doesn't have lung disease. It shouldn't matter. Right?
- How can I improve the outcome(s) for my patient?

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Post-op Pulmonary Complications

- Varying levels of severity
- Post op hypoxia/hypercarbia
- Pneumonia
- Need for supplemental O2 for prolonged period
- Atelectasis
- Non-invasive or invasive mechanical ventilation

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Risk Factors for PPC

Table 1. Risk Factors for Postoperative Pulmonary Complications

Patient Characteristics	Preoperative Testing	Surgery	Anesthetic Management
Age	Low albumin	Open thoracic surgery	General anesthesia
Male sex	Low Spo_2 (≤95%)	Cardiac surgery	High respiratory driving pressure (≥13 cm H_2O)
ASA class ≥3	Anemia (Hb <10 g/dl)	Open upper abdominal surgery	High inspiratory oxygen fraction
Previous respiratory infection		Major vascular surgery	High volume of crystalloid administration
Functional dependency		Neurosurgery	Erythrocyte transfusion
Congestive heart failure		Urology	Residual neuromuscular blockade
COPD		Duration of surgery >2 h	Nasogastric tube use
Smoking		Emergent surgery	
Renal failure			
Gastroesophageal reflux disease			
Weight loss			

Respiratory driving pressure is defined as inspiratory plateau airway pressure minus positive end-expiratory pressure.
ASA = American Society of Anesthesiologists; COPD = chronic obstructive pulmonary disease; Hb = hemoglobin concentration; Spo_2 = oxygen saturation as measured by pulse oximetry.

Guldner et al. *"Intraoperative Protective Mechanical Ventilation for Prevention of Postoperative Pulmonary Complications"*. Anesthesiology, Sept. 2015, 123(3), 691-713.

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Acute Respiratory Distress Syndrome

- Most severe form of lung dysfunction and most dreaded post operative pulmonary complication
  - Very uncommon, incidence around 0.2% in postoperative period
- Levels from mild to severe.
- Grading depends upon P/F ratio
- Has high morbidity and mortality. Mortality still around 50%

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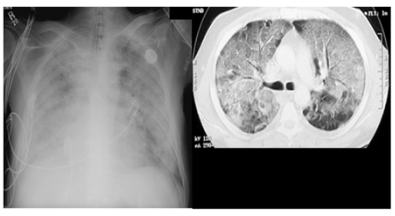
Acute Respiratory Distress Syndrome



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ARDSNet Protocol

- ARDSNet trial showed that lung protective strategies resulted in improved outcomes for patients with ARDS
- LPV defined as 4-6 ml/kg PBW
- PEEP levels at moderate to high levels. Depend upon FiO2
- Goal is to limit peak and plateau pressure
- Reduce mechanical strain on ventilated areas. “Baby lung”

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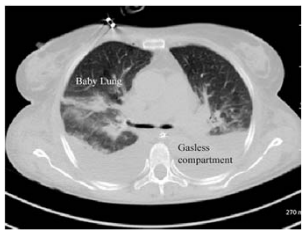
ARDS



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LPV without ARDS?

- Due to results of ARDSNet, ICU ventilation strategies changed
  - Push towards using lower TV, higher PEEP
  - TV of 6-8 ml/kg PBW
- Question if LPV would be beneficial in OR setting
  - Most patients without lung issues in OR setting
- Any improvement or reduction in PPC?
- Culture change needed

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LPV for OR

- Any benefit to using LPV vs high TV with ZEEP

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

A Trial of Intraoperative Low-Tidal-Volume Ventilation in Abdominal Surgery

Emmanuel Futier, M.D., Jean-Michel Constantin, M.D., Ph.D., Catherine Paugam-Burtz, M.D., Ph.D., Julien Pascal, M.D., Mathilde Eurin, M.D., Arthur Neuschwander, M.D., Emmanuel Marret, M.D., Marc Beaussier, M.D., Ph.D., Christophe Gutton, M.D., Jean-Yves Lefrant, M.D., Ph.D., Bernard Allaouchiche, M.D., Ph.D., Daniel Verzilli, M.D., Marc Leone, M.D., Ph.D., Audrey De Jong, M.D., Jean-Etienne Bazin, M.D., Ph.D., Bruno Pereira, Ph.D., and Samir Jaber, M.D., Ph.D., for the IMPROVE Study Group*

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IMPROVE Trial

- Compared LPV (6-8 ml/kg + PEEP + recruitment) vs traditional mechanical ventilation (TV >10 ml/kg and no PEEP)
- Patients at risk for pulmonary complications
- Abdominal surgery patients
- Statistically significant reduction in need for invasive ventilation and drastic reduction in other PPC

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IMPROVE Trial

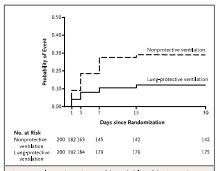

Figure 2. Kaplan–Meier Estimates of the Probability of the Composite Primary Outcome.

Data for the Kaplan–Meier estimates of the probability of the composite primary outcome of major pulmonary or extrapulmonary complications were censored at 30 days after surgery. Major pulmonary complications included pneumonia or the need for invasive or noninvasive ventilation for acute respiratory failure. Major extrapulmonary complications were sepsis, severe sepsis, septic shock, and death. P<0.001 by the log-rank test for the between-group difference in the probability of the primary outcome.

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Protective Mechanical Ventilation during General Anesthesia for Open Abdominal Surgery Improves Postoperative Pulmonary Function

Paolo Severgnini, M.D.,* Gabriele Selmo, M.D.,* Christian Lanza, M.D.,* Alessandro Chiesa, M.D.,* Alice Frigerio, M.D.,* Alessandro Bacuzzi, M.D.,* Gianlorenzo Dionigi, M.D., Ph.D.,‡ Raffaele Novario, R.H.,§ Cesare Gregoretti, M.D.,‖ Marcelo Gama de Abreu, M.D., Ph.D.,# Marcus J. Schultz, M.D., Ph.D.,** Samir Jaber, M.D., Ph.D.,†† Emmanuel Futier, M.D.,‡‡ Maurizio Chiaranda, M.D., Ph.D.,§§ Paolo Pelosi, M.D.,‖‖

- Similar study to IMPROVE trial
- Used recruitment maneuvers as well
- Significant reduction in need for supplemental O2 and CXR changes up to 5 days post operatively

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Driving Pressure

The NEW ENGLAND JOURNAL of MEDICINE

SPECIAL ARTICLE

Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.

ABSTRACT

- Why is this important?
- Driving pressure directly related to VILI, even in healthy lungs
- Increased incidence of development of ARDS
- Similar findings found by Blum et al reviewing over 50K cases

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Driving Pressure

- Driving pressure = C_{rs}/TV or P_{plat} – PEEP
- Patients with driving pressure under 15 cmH20 had better outcomes and less time on mechanical ventilation
- Does this correlate to the OR patient?

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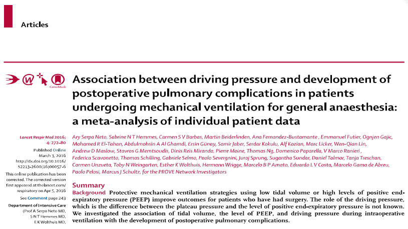
Driving Pressure in OR


Articles

Association between driving pressure and development of postoperative pulmonary complications in patients undergoing mechanical ventilation for general anaesthesia: a meta-analysis of individual patient data

Lancet Respir Med 2016; 4: 272–80

Published Online March 3, 2016 http://dx.doi.org/10.1016/S2213-2600(16)00057-6

This online publication has been corrected. The corrected version first appeared at thelancet.com/respiratory on Apr 5, 2016

See Comment page 243

Department of Intensive Care (Prof A Serpa Neto MD, S N T Hemmes MD, E K Wolthuis MD,

Ary Serpa Neto, Sabrine N T Hemmes, Carmen S V Barbas, Martin Beiderlinden, Ana Fernandez-Bustamante , Emmanuel Futier, Ognjen Gajic, Mohamed R El-Tahan, Abdulmohsin A Al Ghamdi, Ersin Günay, Samir Jaber, Serdar Kokulu, Alf Kozian, Marc Licker, Wen-Qian Lin, Andrew D Maslow, Stavros G Memtsoudis, Dinis Reis Miranda, Pierre Moine, Thomas Ng, Domenico Paparella, V Marco Ranieri , Federica Scavonetto, Thomas Schilling, Gabriele Selmo, Paolo Severgnini, Juraj Sprung, Sugantha Sundar, Daniel Talmor, Tanja Treschan, Carmen Unzueta, Toby N Weingarten, Esther K Wolthuis, Hermann Wrigge, Marcelo B P Amato, Eduardo L V Costa, Marcelo Gama de Abreu, Paolo Pelosi, Marcus J Schultz, for the PROVE Network Investigators

Summary

Background Protective mechanical ventilation strategies using low tidal volume or high levels of positive end-expiratory pressure (PEEP) improve outcomes for patients who have had surgery. The role of the driving pressure, which is the difference between the plateau pressure and the level of positive end-expiratory pressure is not known. We investigated the association of tidal volume, the level of PEEP, and driving pressure during intraoperative ventilation with the development of postoperative pulmonary complications.

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Driving Pressure

- Neto et al. showed that driving pressure intraoperatively was significantly associated with PPC
- Meta-analysis of 17 randomized control trials, 2250 patients
- Wide variety of cases
- More predictive than any other ventilation variable studied

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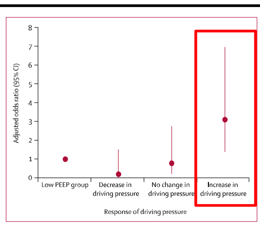

Figure 2: **Odds of postoperative pulmonary complications according to response of driving pressure after increase of PEEP**
PEEP=positive end-expiratory pressure.

Neto et al. "Association between driving pressure and development of post operative pulmonary complications in patients undergoing mechanical ventilation for general anesthesia: a meta-analysis of individual patient data". *Lancet Respir Med.* 2016; 4:272-80.

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Table 2. Intraoperative data

	High volume with ZEEP (n=22)	Low volume with 8 cm H_2O PEEP (n=20)	Low volume with 8 cm H_2O PEEP and recruitment (n=21)	*P* Value
Tidal volume, median [IQR], ml	580 [490-600]	380 [330-460]	440 [340-470]	<0.0001
Tidal volume, median [IQR], ml/kg of predicted body weight	9.19 [9.06-9.26]	6.93 [6.65-7.07]	7.01 [6.89-7.1]	<0.0001
PEEP, median [IQR], cm H_2O				
Baseline	2 [2-2]	8 [8-8]	8 [8-8]	<0.0001
End of surgery	1.5 [1-2]	8 [8-8]	8 [8-9]	<0.0001
Peak, median [IQR], cm H_2O				
Baseline	14 [13-17]	16 [15-17]	16 [16-17]	0.03
End of surgery	14 [12-17]	16 [16-17]	15 [15-17]	0.03
Plateau pressure, median [IQR], cm H_2O				
Baseline	12.5 [11-15]	14.5 [14-15.5]	15 [15-16]	0.003
End of surgery	13 [11-16]	15 [15-16]	14 [13-16]	0.01
Raw, cm $H_2O/(L \cdot s)$				
Baseline median [IQR],	11.50 [9-14]	9 [8-10.50]	9 [7-12]	0.04
End of surgery, (mean ± SD)	8.64±2.57	6.8±1.96	7.43±2.31	0.004
$P_{ET}CO_2$, mmHg				
Baseline, median [IQR]	32.50 [30-37]	35 [31.50-36.50]	33 [32-35]	0.65
End of surgery, (mean ± SD)	31.86±3.36	34.6±2.74	34.33±2.5	0.005
Duration of mechanical ventilation, median [IQR], h	2.87 [2.25-3.25]	3.32 [2.67-3.77]	3.45 [2.50-3.62]	0.46
Duration of surgery, median [IQR], h	2.48 [2-3.25]	3.09 [2.59-3.71]	3 [2.15-3.47]	0.22
Duration of extubation, median [IQR], min	15.50 [12-19]	18.50 [14.50-22.50]	20 [16-24]	0.11

IQR = interquartile range.

Pi et al. "Low tidal volume with PEEP and recruitment expedite the recovery of pulmonary function". Int J Clin Exp Pathol 2015;8(11):14305-14314

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Does PEEP Matter?

- With low tidal volumes and moderate levels of PEEP (6-10 cmH20) these studies suggested that PEEP was the protective factor
- PROVHILO trial looked into LPV with either high PEEP (10-12 cmH20) or low PEEP (0-2 cmH20)
- No outcome difference between the groups after 5 hospital days
- Low PEEP group had higher incidence rescue therapy for hypoxemia (increase in PEEP + recruitment)
- Patients receiving low TV and low PEEP found to have increased 30 day mortality

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iPROVE Trial

Individualised perioperative open-lung approach versus standard protective ventilation in abdominal surgery (iPROVE): a randomised controlled trial

*Carlos Ferrando, Marina Soro, Carmen Unzueta, Fernando Suarez-Sipmann, Jaume Canet, Julián Librero, Natividad Pozo, Salvador Peiró, Alicia Llombart, Irene León, Inmaculada India, Cesar Aldecoa, Oscar Díaz-Cambronero, David Pestaña, Francisco J Redondo, Ignacio Garutti, Jaume Balust, Jose I García, Maite Ibáñez, Manuel Granell, Aurelio Rodríguez, Lucía Gallego, Manuel de la Matta, Rafael Gonzalez, Andrea Brunelli, Javier García, Lucas Rovira, Francisco Barrios, Vicente Torres, Samuel Hernández, Estefanía Gracia, Marta Giné, María García, Nuria García, Lisset Miguel, Sergio Sánchez, Patricia Piñeiro, Roger Pujol, Santiago García-del-Valle, José Valdivia, María J Hernández, Oto Padrón, Ana Colás, Jaume Puig, Gonzalo Azparren, Gerardo Tusman, Jesús Villar, Javier Belda, on behalf of the Individualized PeRioperative Open-lung VEntilation (iPROVE) Network**

- Looked at open lung approach to optimize PEEP intra and post operatively
- Patients without significant lung issues
- Abdominal surgery procedures
- 4 arms of the trial: OLA + individualized CPAP during and after, OLA + standardized CPAP during and after, standard LPV + CPAP 5 cmH20 during and after, and standard LPV + O2 therapy after surgery

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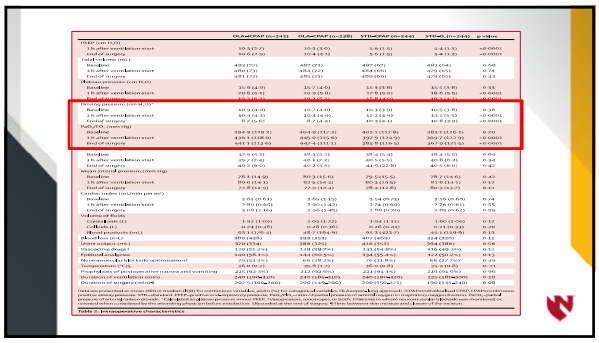

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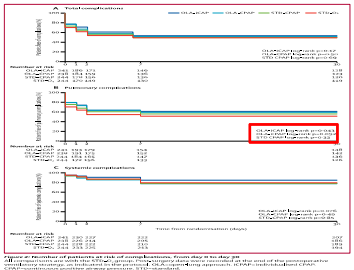
iPROVE Results



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iPROVE

- Standard ventilation + CPAP and standard ventilation + O2 therapy groups both required rescue maneuvers intraoperatively due to hypoxemia
- Overall had increased incidence of pulmonary complications in standard groups compared to OLA groups
- Study overall shows no significant difference in outcomes as primary outcome was total complications postoperatively

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What about One Lung Ventilation?

- Patients at high risk for pulmonary complications
  - Direct surgical insult
  - Pre-existing lung disease
  - Very painful incisions
  - Large inflammatory response due to surgery and mechanical ventilation
- LPV has been shown to reduce PPC in this patient population

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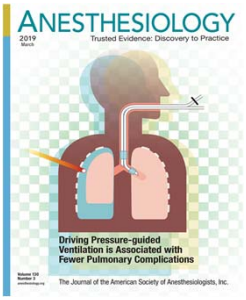

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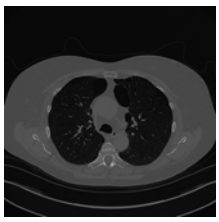
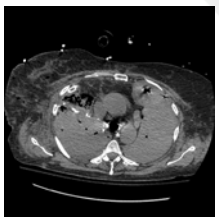
RULobectomy - ARDS





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Driving Pressure in OLV

- Randomized trial comparing LPV versus driving pressure guided ventilation
- Studied due to still high rates of pulmonary complications in this population despite LPV
- PEEP maintained at 5 cmH20 for LPV group after recruitment maneuver in lateral position
- Driving pressure group had PEEP determined after calculating driving pressure at varying levels of PEEP from 2-10 cmH20.

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ANESTHESIOLOGY
The Journal of the American Society of Anesthesiologists, Inc.
From: Driving Pressure during Thoracic Surgery:A Randomized Clinical Trial
Anesthes. 2019;130(3):385-393. doi:10.1097/ALN.0000000000002600

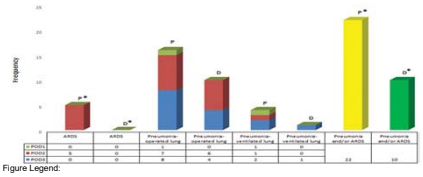

Figure Legend:
The onset and frequency of lung lesions. *Chi-square test for comparing variables, P < 0.05. ARDS, acute respiratory distress syndrome; D, driving pressure group; P, protective ventilation group; POD 1, postoperative day 1; POD 2, postoperative day 2; POD 3, postoperative day 3.

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Driving Pressure

- PEEP of 5 in LPV group and ideal PEEP of 3 in driving pressure group
- Lower PEEP in driving pressure group thought to be due to intrinsic PEEP that occurs during OLV and lateral position
- Driving pressure difference of 10 cmH20 in LPV vs 9 cmH20 in driving pressure group
  - Does a difference of 1 cmH20 make a difference?
  - Mortality risk increases 3.4% for each elevation of driving pressure by 1 point
  - Incidence of PPC increases with increase in driving pressure

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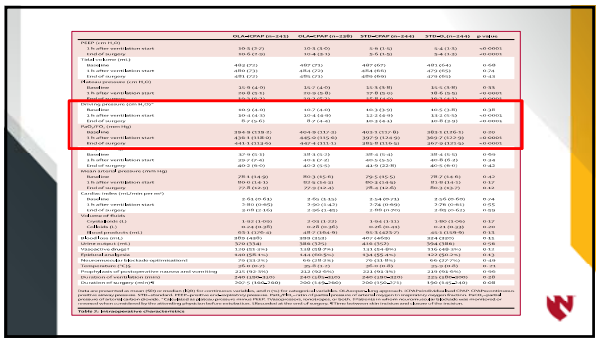

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Conclusions

- LPV can and will prevent postoperative pulmonary complications
  - Reduce morbidity and mortality
  - Reduce costs for hospital and patient
- 6-8 ml/kg PBW for TV
- PEEP can vary in amount used but studies recommend it decreases PPC
  - Studies looking further into "individualized" PEEP ongoing
  - Levels of 6-10 cmH20 recommended
- Driving pressure may be the parameter to watch
- More research is needed! Need more RCTs. PROTHOR coming soon.

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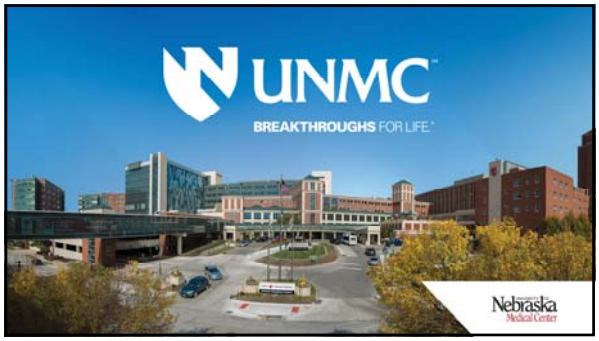

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