This article explores the question of the implementation of lung protective ventilation in the OR. The discussion on how to ventilate surgical patients intraoperatively to minimize postoperative pulmonary complications has been vivid in the past years. Various randomized controlled trials (RTCs) and reviews have been conducted to bring light into the dark. However, research has not fully resolved clinical equipoise, yet. Some parameters of ventilation are proven as levers for protecting patients’ lungs during surgery, some remain unclear and require further research. However, all in all it seems to be common sense that general anesthesia impairs lung function and ventilation plays a significant role in causing these impairments. Although results from research conducted on this topic is by far not univocal, the evidence gained during the past years mandate the use of lung protective strategies in surgical patients even though not all questions have been sufficiently answered yet.

The question is how current approaches can be implemented effectively. Various other clinical procedures have shown that, although striking evidence is in place, recommendations and even guidelines are not fully applied on a routine basis in clinical practice.

**DISCUSSION ON PROTECTIVE VENTILATION IN THE OR**

In the discussion on intraoperative lung protection, research focusses on specific parameters that are expected to have an influence on the incidence of postoperative pulmonary complications, either individually or in conjunction with each other. Under discussion is the size of tidal volumes (Vt), the use and the level of positive end-expiratory pressure (PEEP), the applied oxygen fraction, recruitment maneuvers and recently the plateau- and driving pressures.

**TIDAL VOLUME.**

High Vt has already been described for quite some time to be particularly dangerous for ARDS patients and low Vt ventilation has become a standard of care for these patients on ICU as evidence demonstrated a clear reduction of mortality. But evidence has not only demonstrated the benefits of low Vt for ARDS patients, but also for critically ill patients without lung injury. But for these patients, low Vt strategies have not yet become standard of care.

In the OR, clinical trials have suggested that lung protective strategies encompassing reduced Vt have a positive effect on lung function and the incidence of postoperative pulmonary complications (PPCs). Three RCTs have demonstrated positive effects of low Vt in patients undergoing abdominal surgery and spinal surgery. Tidal volumes in these trials were as low as 6-7ml/kg predicted bodyweight (PBW).

The two large European trials, known as IMPROVE and PROVHILO, have both advocated that lung protective ventilation in the OR should include low Vt, but showed contradicting results with respect to other components of lung protection, namely PEEP and recruitment maneuvers (RM). A recent meta-analysis stated the harmful effects of high Vt even under short-term ventilation for general anesthesia for surgery advocating relatively low Vt of 6-8ml/kg PBW. A very recent RCT on lung protective ventilation further suggests this approach for healthy patients undergoing laparoscopic surgery.
TIDAL VOLUME & PREDICTED BODYWEIGHT.

It is well known that tidal volumes should not be calculated based on actual but on predicted ideal bodyweight, as suggested above. This is important as the application of tidal volumes as low as 6-8ml/kg result in tidal volumes that may appear very low, probably lower than many would expect. In addition, there seems to be no agreement on a uniform way to calculate the PBW. The equations found in literature are inconsistent and result in markedly different tidal volumes. An article from 2015 listed and compared various equations and recommended the NIH/NHLBI ARDSNet definition:

\[
\begin{align*}
\text{Men: } & 45.5 + 0.905 \times ([\text{height in cm}] - 152.4) \\
\text{Women: } & 45.5 + 0.905 \times ([\text{height in cm}] - 152.4)
\end{align*}
\]

PEEP.

Whereas most research seems to be univocal with respect to tidal volumes, the use and the benefit of PEEP appears to be still controversial. For patients with moderate to severe ARDS, a meta-analysis has suggested a benefit from higher PEEP levels. But three independent RCTs failed to demonstrate definitive benefit. In critically ill patients without ARDS one study showed a benefit of a PEEP of 8-cmH2O compared to zero PEEP (ZEEP) with regards to the incidence of ventilator-associated pneumonia and the risk of hypoxemia, but not with respect to outcomes. Another trial could not demonstrate a positive effect of a PEEP of 8-cmH2O on the occurrence of ARDS or other associated complications. But another RCT found an independent association between higher PEEP levels and the development of lung injury when comparing Vt of 6 and 10 ml/kg PBW in the critically ill patient without ARDS.9, 31, 32, 33, 34, 35, 36, 37

For the perioperative ventilation, the available research does not give a clear answer on what the ideal PEEP is. The above mentioned three RCTs compared bundles of lung protective measures, also including different levels of PEEP. This made it almost impossible to draw any conclusion about the individual effect of this parameter.

PEEP was also the controversial point when comparing the two big European trials, PROVHILO and IMPROVE.12, 13 While IMPROVE recommended a moderate PEEP level to keep recruited lungs open and to prevent further collapse, the PROVHILO trial could not demonstrate any benefit from higher PEEP levels of 12-cmH2O compared to low PEEP levels of 2-cmH2O, but high PEEP levels produced more intraoperative hypotension and a higher need for vasoactive drugs.10, 13 The above mentioned meta-analysis cites recent findings that also suggest that higher levels of PEEP (10-12-cmH2O) do not protect against PPCs and may even cause harm, at least in the non-obese patient.14 The above mentioned recent RCT on lung protective ventilation in patients undergoing laparoscopic surgery found that low VT with a moderate PEEP of 5-cmH2O was associated with less incidences of pulmonary complications compared to conventional ventilation approaches with high VT with RM and no PEEP.15 So the discussion currently appears to tend toward moderate to low PEEP.15, 30

Some authors mention, that an appropriate PEEP has to be chosen, but leave the question open what an appropriate PEEP is. In a recent commentary, Pelosi and Ball have risen the question if it is time to talk about tailored protective ventilation, and demand further studies in particular on the role of patient-tailored PEEP settings.15 This is also backed by a recent comprehensive review stating that PEEP should be chosen according to the patient's particular characteristics, to specifics of the surgical approach and the patients' position.30 From a clinical routine perspective, Dr. Chris Thompson, Senior Staff Specialist at Royal Prince Alfred Hospital, Clinical Lecturer at the University of Sydney, Australia, has commented on this topic in his lecture at the ANZCA Congress 2015 in New Zealand. In his lecture, he gave practical insights into his approaches to protective ventilation including patient individual PEEP titration. It might be worth watching his lecture on YouTube.26

PLATEAU PRESSURE & DRIVING PRESSURE.

Two parameters have seldom appeared in the discussion on protective ventilation: plateau pressure and driving pressure, which is defined as plateau pressure minus PEEP. A recent hospital based registry study analyzing 69,265 consecutive patients undergoing non-cardiac surgery (2007 – 2014) with general anesthesia and endotracheal intubation found, that there is a moderate, statistically significant dose dependent relation between the risk of respiratory complications and the level of plateau pressure. The driving pressure was stated to have an effect on the occurrence of respiratory complication comparable to the plateau pressure. A median plateau pressure of less than 16-cmH2O was identified as being protective and resulting in no increased risk of ventilator associated postoperative respiratory complications. A very interesting finding was, that there was no significant statistical association between Vt and the incidence of PPCs.27

Ball & Pelosi, whose earlier mentioned comment refers to this study, stated that this finding suggests that the harmful effect of tidal volume dynamic strain might be mediated by an increase in plateau pressure linked to lung compliance, possibly reflecting lung stress.12

INSPIRED OXYGEN FRACTION (FiO2)

Traditionally a high FiO2 was expected to improve oxygenation and reduce the incidence of PONV as well as surgical site infections. But in the past years a more critical discussion has developed around the inspired oxygen fraction that puts a question mark behind the afore mentioned traditional opinion. Part of this discussion is the assumption that high FiO2 may induce pulmonary dysfunction, e.g. by induction of resorption atelectasis in unstable aveoli, and pulmonary injury, at least in part caused by oxidative stress via increased levels of reactive oxygen-derived free radicals that can overcharge natural
antioxidant defenses and injure cellular structures. Furthermore, evidence suggests that high FiO₂ in conjunction with high blood oxygen is associated with increased mortality in critically ill patients.⁶

For intraoperative ventilation, Güldner et al recommend to use an FiO₂ of ≥0.4 to keep SpO₂ ≥92% and increase FiO₂ first in case of hypoxemia (if other reasons are ruled out).³⁰ This applies to non-obese, healthy patients. There may be good reasons for higher oxygen fractions depending on the patient or the surgical procedure.

RECRUITMENT
Most studies cited herein have not specifically studied how, when and for which patients to best apply recruitment. However, PEEP has been described as being most effective when a recruitment maneuver has been carried out before. Güldner et al recommend to do so during tidal ventilation using an incremental approach with pressure controlled ventilation keeping plateau pressure constant at 15-20cmH₂O and gradually increasing PEEP to 20cmH₂O in steps of 5cmH₂O at 30-60 seconds per step. PEEP and tidal volume are adjusted to desired levels after up to 5 breaths at the PEEP level that achieves the targeted inspiratory pressure. This approach shows similarities with the above mentioned approach to PEEP titration suggested by Chris Thompson.²⁶ Recruitment of atelectatic lung areas may require airway pressures of 40 mbar or even higher.³⁰ However, as we believe recruitment is a quite important topic in the discussion on intraoperative lung protection, we will provide you with a separate review of literature at a later point in time.

RECOMMENDATIONS FROM LITERATURE
Based on current evidence, Ball & Pelosi suggest the following parameters to be included into a protective ventilation strategy which is largely backed by recommendations by Filho & Serpa Neto published in a recent commentary³⁰ and Güldner et al published in their recent Review²⁶:
- Low tidal volumes of 6-8ml/kg PBW¹⁰, ²⁶
- Plateau pressure (<16cmH₂O) and low driving pressure, whenever possible¹⁰, ²⁶
- Low PEEP ≤ 5cmH₂O or even ≤ 2cmH₂O²⁶ without recruitment¹⁰, ³⁰
- PEEP between 5-10cmH₂O to be considered in obese patients & for patients undergoing laparoscopic surgery in Trendelenburg position for >4h¹⁰
- FiO₂ ≥0.4 to keep SpO₂ ≥92%²⁶
- No recruitment maneuver as initial measure³⁰
- In case of hypoxemia (if other causes are ruled out and if not contraindicated), FiO₂ should be increased first, followed by increase of PEEP and incremental recruitment maneuver.³⁰

SPONTANEOUS BREATHING – A DIFFERENT ASPECT OF PROTECTIVE VENTILATION IN THE OR
Various aspects of lung protection during general anesthesia ventilation have been discussed in the past years. We have gathered evidence insights and recommendations from literature for you in the above paragraphs. This discussion mainly concentrated on controlled mechanical ventilation, which is quite clear as many surgical procedures require neuromuscular relaxation and consequently call for protective methods of mechanical ventilation need to be determined.

But it should be considered that neuromuscular relaxation and subsequent (mandatory) positive pressure ventilation is appears to be a significant factor itself leading to respiratory impairment and potentially to the above cited postoperative pulmonary complications that protective ventilation intends to counteract. Therefore, it seem not too far-fetched to ask, whether spontaneous breathing either as early as possible towards the end of general anesthesia or even already soon after securing the airway may be more beneficial. The following shall briefly highlight what the literature says and what the opinion of clinicians is who have worked on this topic for the past years...

UNEVEN DISTRIBUTION...
Imaging studies in animals have demonstrated that ventilation is not physiologically distributed during continuous mandatory ventilation (CMV). During CMV, ventilation is being shifted to the anterior, nondependent and less perfused lung regions leading to the well described ventilation/perfusion (V/Q) mismatch.²⁵ This also applies to both, anesthetized patients with healthy lungs and patients with substantial pulmonary dysfunction. The reason for this supposedly lies in the role of the diaphragm. When pharmacologically relaxed, the intra-abdominal hydrostatic pressure will push against the diaphragm and move it more cranially – with increasing the pressure from anterior to posterior. This counters or even prevents diaphragm movement in the dependent lung regions resulting into ventilation being shifted to the nondependent lung regions and leaving dorsal lung regions close to the diaphragm being less ventilated or atelectatic. In due course mechanically administered tidal volume goes primarily into the anterior, nondependent and less perfused parts of the lung leading to the afore mentioned V/Q mismatch.²⁴

... GETTING EVEN.
While breathing spontaneously, the posterior parts of the diaphragm move more than the anterior tendon plate resulting in better ventilation of the dependent lung regions even when supine. This results in a better V/Q matching as the diaphragm is able to oppose alveolar compression.²⁵, ²⁴ The improved aeration of the juxtadiaphragmatic lung regions is the reason for the improved functional residual capacity (FRC) associated with spontaneous breathing.²⁵
DIAPHRAGMATIC EXCURSION.
The above was also confirmed in a research studying diaphragmatic excursion by diaphragmatic fluoroscopy during spontaneous breathing and during positive pressure ventilation. The diaphragm was divided into three segments: top (ventral, nondependent), middle and bottom (dorsal, dependent) in order to analyze differences. During normal spontaneous breathing, total diaphragmatic excursion was significantly greater compared to positive pressure breaths. The data from this study clearly show, that when breathing spontaneously, most diaphragmatic excursion is being observed in the bottom, dependent region, no matter if it was a normal breath or a deep breath. During positive pressure ventilation, excursion of the diaphragm was less in the bottom, dependent part but rather at the top, nondependent part when lower tidal volumes were applied. Only when having applied larger tidal volumes, diaphragmatic excursion was more or less equal in top and the bottom part of the diaphragm.21 This may be remarkable having the discussion on lung protective ventilation in mind which demands for low tidal volumes.

SUPPORT NEEDED.
It appears that spontaneous breathing potentially leads to better ventilatory conditions compared to CMV. But during surgery, anesthetic drugs – especially opioids – impair spontaneous breathing by causing respiratory depression.27 When comparing general anesthesia using Isoflurane or Sevoflurane with either positive pressure ventilation (PPV) or spontaneous breathing, it was found that PPV produced better respiratory results compared to spontaneous breathing, specifically with respect to oxygenation and etCO₂. No differences were observed with regards to hemodynamic parameters. However, in this study, spontaneous breathing attempts were not actively supported by any means.28

Brimacombe et al tested if pressure support ventilation (PSV) with PEEP would achieve better results compared to the application of CPAP only, without any tidal support. The results clearly show that PSV results in higher oxygenation saturation, lower etCO₂ values and higher expired tidal volumes compared to CPAP without tidal support thus providing more effective gas exchange.27 In another trial, Bosek et al found that a PSV with a pressure titrated to produce a near normal (physiological) V₁ improves the efficiency of spontaneous breathing during inhalational anesthesia by lowering respiratory rate (RR) and PaCO₂ while preserving hemodynamic homeostasis.29

But there is another aspect to intraoperative spontaneous breathing that extends into the postoperative period. The above mentioned trial by Keller et al also found that time to emerge from general anesthesia using Sevoflurane shortened from 12 minutes down to 6 minutes when patients were breathing spontaneously during general anesthesia.28 This finding was just recently confirmed by an RCT by Capdevilla et al suggesting that intra-operative PSV in patients with laryngeal mask (LMA) reduces anesthesia emergence time and Propofol consumption compared to continuous mandatory ventilation. In addition they found, that PSV improved respiratory function and did not cause adverse effects.30

The above intends to raise spontaneous breathing as a potentially interesting component of lung protective ventilation in the OR resulting in a better ventilation distribution. However, although there is also good reason and absolute necessity for mechanical ventilation for various patients and surgical procedures, spontaneous breathing might be a good option in the future for even more indications as anticipated today. Further research is required to determine these indications and provide evidence for the effectiveness of spontaneous breathing in intraoperative ventilation.

A DISTRACTING THOUGHT ON DIFFICULTIES DEPLOYING PROTECTIVE VENTILATION
The current, vivid discussion on lung protective ventilation in the OR stresses the importance of this topic and the question may be raised on how implementation into daily clinical routine can be achieved. Looking at other procedures, such as active warming of patients in the OR, evidence is clear and even guidelines demand respective measures. But deployment into daily clinical routine appears to be hampered for various reasons. We eagerly await the results of an international, prospective, observational, multicenter cohort study intending to research the current mechanical ventilation practices during general anesthesia to get solid insights into the degree of protective ventilation deployment in the OR.31 However, clinicians may need to consider a growing number of guidelines and standardized procedures in their daily clinical routine to fulfill the so called standard of care in the future. That specifically applies to the fairly complex topic of ventilation in the OR. Here’s a different thought of what could hamper consequent implementation of protective ventilation...

COMPLEXITY.
The workplace of anesthesiologists in the OR is very complex and overloaded with information and multitasking necessities. The number of tasks, anesthesiologists have to perform daily has increased substantially over the past decades, also demanding to continuously multitask under difficult conditions. In an article by Thomas M. Hemmerling he referred to the anesthesiologist as the pilot in the physiological biosphere of modern acute care medicine.32 When combining the above with the concepts of distraction and mental workload that anesthesiologists are exposed to, potentially negative impact on patient care is imaginable.
DISTRACTION.

Distractions are cited as contributory to healthcare-associated errors in a large portion of incidents including or involving the anesthesiologist.¹ The safe administration of anesthesia requires vigilance, time-sharing among multiple tasks and the ability to rapidly make decisions and take actions.² It is well recognized in other industries, such as aviation, that distraction increases the risk of error.

Within anesthesia, distraction has been implicated in the development of critical incidences.² Another aspect has the potential to make the entire mixture quite delicate. Looking into literature, distraction of the anesthesiologist has already been researched. One observational study has found, that on average 34 distracting events were observed in cases with a mean duration of 103 minutes. Sources of distraction included other anesthesiologists, the circulating nurse, visitors and the surgeon. But events with the highest level of distraction requiring immediate attention originated from OR equipment (alarms, noises) and other anesthesiologists. The spread of distractions across the phases of Anesthesia was equal. Another study found that one distracting even happened every 4 minutes and 23 seconds, most frequently during emergence with one event every 2 minutes.³ In the first study mentioned above, approximately 8 distracting events per case were judged to be detrimental to current patient care.¹ The second study judged 22% of all observed distracting events to have a negative effect.²

Disturbing events during key anesthetic interventions were observed relatively frequently, with about 2 events per case. The role of general background noise in the OR is controversial. General background theatre noise has been associated with deterioration in mental efficiency and short-term memory. But looking into the nature of different tasks, noise does not always have a negative effect. Low demand tasks may be performed better with increasing levels of external stimulation (conversations, noise and music) up to a certain point, but higher demand tasks may suffer with the same degree of external stimulation.¹

As the administration of a general anesthesia, including protective ventilation from our perspective needs to be considered as a high demand task that requires vigilance and close monitoring of all parameters that can be compromised by distractions as described above. Reported incidences may underline this thought. In one case in Germany, an anesthesiologist forgot to switch on the anesthesia device while the patient was intubated. The reported reasons were distraction and ambient noise level in the OR.¹ In another case, the anesthesiologist forgot to re-start the ventilation after deliberately suspend ventilation during cardiac surgery. Among the reasons reported: many distractions.⁴

The above mentioned events can surely not only be attributed to inattention of the anesthesiologist or other inadequate behavior. But they may be a result of the above mentioned contributing factors: Complex work environment meets information overload meets constant multitasking meets frequent distraction. Another factor that has been studies but apparently not yet clearly proven to be a factor contributing to human error in anesthesia is the mental workload.⁵ But methods to measure mental workload have been researched and further research is desirable.⁵ However, all this calls for the medical device industry to come up with devices that reduce information overload, are being used intuitively and assist with tasks that can be carried out following evidence based rule sets. Maybe assistance systems that take over those tasks but leave the anesthesiologist in the driver seat, easing the compliance with the standard of care, freeing up cognitive resources of the anesthesiologist and reducing the potential negative effects distractions in the OR may help reducing errors and gain importance.

³ CIRSmedical / CIRS AINS, Case No. 28440
⁴ CIRSmedical / CIRS AINS, Case No. 110537
⁵ CIRSmedical / CIRS AINS, Case No. 1292


26 Dr. Chris Thompson, Senior Staff Specialist at Royal Prince Alfred Hospital, Clinical Lecturer at the University of Sydney, Australia, Lecture at the ANZCA Congress 2015 in New Zealand, "Ventilation Techniques – A Practical Workshop”


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