

Perioperative lung protection for obese patients

Effective Pre-oxygenation and Induction in Obese Patients

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An increasing number of obese patients will require anesthesia. In this article we will outline some of the challenges for anesthesiologists in regards to pre-oxygenation and induction of obese patients based on selected literature, explore anatomical and physiological backgrounds relevant to general anesthesia, and provide an overview of literature-recommended approaches.

Obese patients impose an increasing challenge on anesthesia care providers. Not only the sheer number of those patients is increasing, but also the management of obese patients during general anesthesia may require different approaches compared to non-obese patients. Therefore, potentially hazardous situations may emerge if these patients are not addressed appropriately.

Obese patients – challenges for anesthesia care providers on the rise

Obesity has become a widespread consequence of worldwide adaptation of Western lifestyle behaviour - and it's still continuing to rise. This development is being observed in various parts of the world and becomes a major challenge for healthcare providers: Hodgson et al. recently reported an obesity prevalence of 32 % in males and 34 % in females in the US. For the UK they reported 25 % in males as well as in females¹. In Germany, 20.8 % of the entire population is reported to be obese, and 37.4 % present with overweight "only"¹⁸. Within the Chinese population, 4-5 % of males and females can be referred to as obese. This includes obesity (BMI ≥ 30 kg/m²) as well as morbid obesity (BMI ≥ 40 kg/m²).

The NHS in the UK reported a 30 % increase in bariatric surgical procedures over the past 10 years and a ten-fold increase in hospital admissions related to obesity. Worldwide, the number of obese people has doubled in the past 35 years - estimated to now reach 671 Million people¹. Obese patients are, therefore, a very common challenge in the hospital today and will be an even greater one in future – for both surgeons and anesthetists in the OR.

Why are the obese patients a challenge?

Apart from their pure weight which makes the general handling and the preparation for surgery more difficult, obese patients impose significant challenges on anesthesia care providers throughout the entire anesthesia process and run at high risk to develop severe intraoperative and postoperative complications.

Distinct changes in anatomy and physiology put obese patients at higher risk for developing hypoxemia during anesthesia induction as well as for intraoperative and postoperative pulmonary complications^{1, 4, 12}. The surgical intervention adds to the challenge, e.g. minimally invasive surgery may impede lung mechanics during pneumoperitoneum⁵.

In anesthesia, the entire process can be affected. Especially if with the standard approach to pre-oxygenation and induction is not working as intended/anticipated. As a result, potentially severe complications such as unexpectedly early arterial oxygen desaturation during endotracheal intubation may arise^{6, 11}. In the subsequent course of the anesthesia, complications leading to post-operative pulmonary complications (PPC) and unscheduled or prolonged ICU stays are possible. Economic implications thus appear to be inevitable.

Based on international literature, this article focuses on the risks and complications associated with obesity in the pre-oxygenation and induction phase. Formation of atelectasis during this phase contributes to these risks of obese patients.

TYPICAL STANDARD APPROACH TO PRE-OXYGENATION AND INDUCTION

Most anesthetists would probably agree that the following sequence is a typical, standard approach to pre-oxygenation and induction

1. Gently lay the mask onto the face of your patient
2. Let the patient breathe normally for 3-5 minutes or let the patient take 5-8 deep breaths
3. Use a high inspiratory oxygen concentration of 100 % (to get the lung filled with oxygen quickly)
4. Administer anesthetic drugs and manually ventilate the patient
5. Intubate the patient, check etCO₂, and auscultate to ensure bilateral ventilation and absence of gastric insufflation
6. Switch to controlled ventilation

In general, the target of the approach is to ensure sufficient oxygenation during the apnea phase when performing endotracheal intubation and to subsequently switch to mechanical ventilation. This procedure may be fine for most healthy, normal-weight subjects as their physiology allows sufficient oxygen stores with this approach. However, literature suggests that this approach may be inadequate for obese or even morbidly obese patients.

Adapted approaches to pre-oxygenation and induction may be needed

Difficult mask ventilation / difficult intubation

Anesthesia care providers may need to calculate a prolonged time to secure airway in obese patients. Obesity and morbid obesity are associated with difficult mask ventilation and potentially difficult intubation. This seems to be frequently underestimated. A prospective trial demonstrated that difficult mask ventilation was encountered in 75 of 1,502 (5 %) patients undergoing surgery with general anesthesia, yet this was anticipated in only 13 of these patients. Juvin et al. reported a 15.5 % rate of difficult intubations in obese patients compared with a 2.2 % rate in lean patients.



A BMI of > 35 was found to be an independent predictor for difficult mask ventilation and difficult or even failed intubation. The risk of serious complications in morbidly obese patients is reported to be 4 times higher than that of lean patients. In a respective review of major complications of airway management in the UK, 25 % of 77 obese patients for whom airway management complications have been reported encountered brain damage or even death¹¹. Another aspect is that the risk of regurgitation and subsequent

aspiration of gastric contents in obese patients may be higher than in lean patients. Therefore, literature can be found recommending the Rapid Sequence Induction (RSI) for obese patients. However, research raises doubts and also states that evidence for this approach is lacking^{21, 22, 23}. All in all it seems that a prolonged time may need to be calculated for airway management and, thus, a longer time of apnea has to be overcome in the obese patient.

Fast desaturation / more atelectasis

Obese patients may desaturate faster. Even with pre-oxygenation, the time of apnea to clinically relevant arterial oxygen desaturation is anticipated to be significantly shorter compared to normal weight patients¹¹. Tanoubi et al. stated that – in obese patients – desaturation can occur 1-2 minutes after apnea begins or within the time for a single attempt of laryngoscopy and tracheal intubation⁶. Even in 85-90 % of healthy non-obese patients atelectasis occurs within minutes after induction of anesthesia: A portion of 15 % of the lung will be atelectatic, in turn resulting in a shunt volume of approx. 5-10 %⁵. In obese patients, the area of anesthesia induced atelectasis is much larger compared to lean patients⁷. Especially during induction, obese and morbidly obese patients are even more prone to develop significant impairment of pulmonary gas exchange and respiratory mechanics. Patients with morbid obesity may even enter the OR with pre-existing atelectasis which is likely to worsen during anesthesia and the postoperative phase when running standard induction and ventilation regimen⁵. It is stated that the risk for arterial desaturation is increased when pre-oxygenation is not performed adequately – and this may happen more frequently than one would think. In a sample of 1,050 healthy patients, inadequate pre-oxygenation ($FeO_2 < 90\%$) was observed in approx. 56 %. In obese patients, decrease of lung volumes (esp. functional residual capacity) and an increased oxygen consumption as well as the heterogeneity of ventilation/perfusion result in inadequate oxygen stores which results in a reduced duration of apnea tolerance¹⁰.

Considering the described challenges associated with obese patients an adapted approach to pre-oxygenation and induction to prevent early desaturation is reasonable to consider. Prior to reviewing options for pre-oxygenation and induction in obese patients suggested by literature, let's review insights from current literature regarding anatomical and physiological changes that may be present in obese patients.

DIFFERENCES IN OBESE PATIENTS ARE SIGNIFICANT

In obese and morbidly obese patients, distinct changes in anatomy and physiology are observed compared to normal weight subjects. These changes result in:

1. Significantly lower oxygen stores
2. Significantly increased work of breathing
3. Increased oxygen consumption.

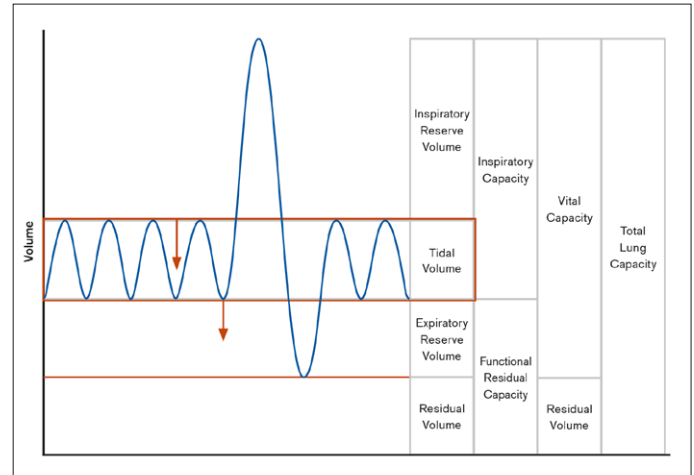
Reasons for decreased oxygen stores and increased work of breathing

Obesity leads to a decreased respiratory system compliance of up to 35 %¹. Compliance is being seen as the stiffness of the respiratory system impacting spontaneous breathing as well as mechanical ventilation¹⁹. According to the literature, the following anatomical changes mainly contribute to this:

- a) Increased mass loading on the chest wall and fat distribution is leading to high pleural pressures¹.
- b) Increased abdominal volume and visceral fat lead to diaphragm elevation and increased diaphragmatic impedance¹. This reduces the efficacy of the diaphragm to about half of that in non-obese patients². The increased abdominal volume also leads to a lumbar kyphosis and thoracic lordosis, increasingly restricting rib movement and resulting in a relative fixation of the thorax in the inspiratory position¹³.
- c) Blood volume may be increased by up to 50 % in obese patients in order to cope with the increased oxygen consumption¹. Almost 50 % of obese patients suffer from hypertension which also affects pulmonary circulation¹³.

A second factor relates to a reduction in lung volumes as a consequence of obesity - apart from the direct impact on the overall compliance of the respiratory system. Although the extremes of lung volumes (residual volume and total lung capacity) seem to remain more or less unaffected, the volumes related to tidal breathing are likely to be compromised^{1, 3, 6, 8}. Specifically the functional residual capacity (FRC) and the expiratory reserve volume (ERV) can be significantly reduced^{1, 3}.

In a study, the non-obese control group presented an FRC of 2861 +/- 682 ml, whereas obese patients showed an FRC of 2173 +/-

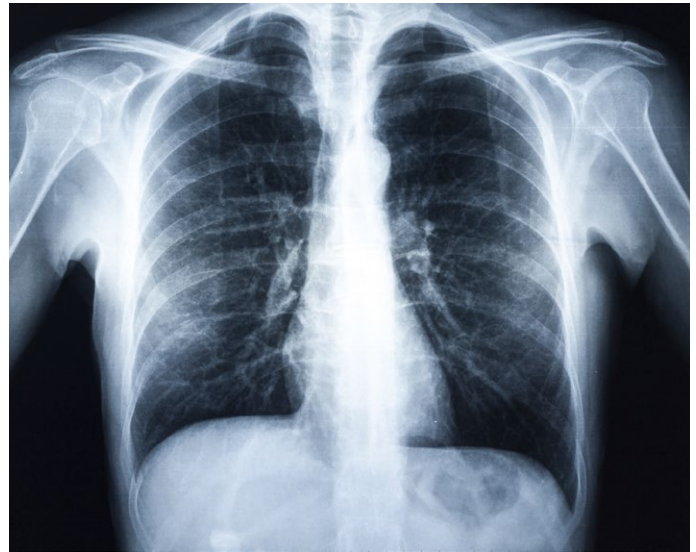
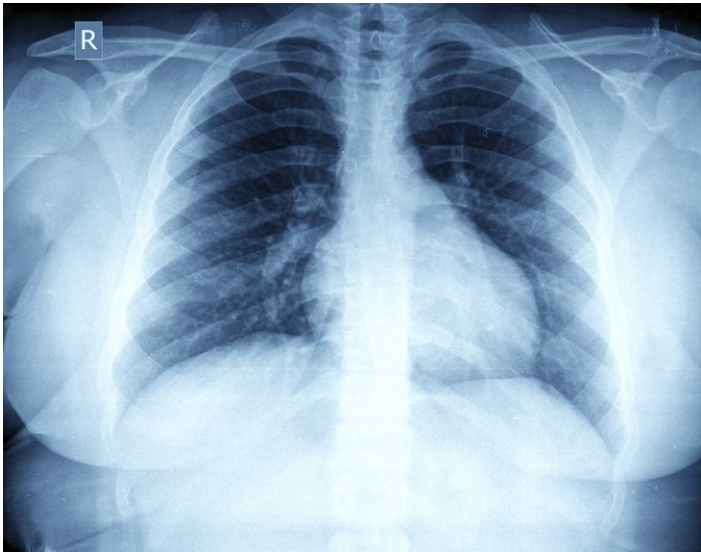


Reduction in FRC is mainly caused by a reduction of expiratory reserve volume. The tidal volume is reduced to breathe more economic but respiratory rate is faster to ensure sufficient ventilation.

403 ml which is 25 % less compared to lean patients. The same study demonstrated that – after induction of anesthesia (with zero PEEP) – the FRC in non-obese patients was reduced by 39 % compared to reference values. In obese patients, the reduction was considerably higher at approximately 59 %⁸. This demonstrates that FRC in obese patients is already lower compared to non-obese prior to induction, but decreases further once anesthesia is induced.

Implications of reduced lung volumes for obese patients

Reduced lung volumes, especially FRC, imply that breathing also happens at lower lung volumes. This is associated with a higher risk for small airway closure and air trapping making obese patients being prone to the formation of atelectasis^{1, 3, 6}. As indicated above, morbidly obese patients will even have atelectasis in the awake with pre-existing atelectasis in the awake and upright position⁵. In addition to that, the anesthesia-induced area of atelectasis is much larger in obese patients compared to lean patients⁷. As a consequence, a reduced FRC can lead to misleading clinical indications of adequate pre-oxygenation. For example, during pre-oxygenation, you will find that wash-in will be faster in patients with a reduced FRC, meaning you will achieve your targeted expiratory oxygen fraction quicker. However this may sound appealing it is important to be aware that this is just a result of reduced oxygen stores in the volume-reduced lung that will in turn result in a shortened duration of apnea without desaturation⁶. As well, negative effects of low end-



Chest x-rays of an obese patient (left) with an elevated diaphragm and a normal weight patient (right) with a normal diaphragm position.

expiratory lung volumes can worsen lung injury during positive pressure ventilation, possibly due to repeated airway closure⁸.

Intrinsic PEEP (PEEPi)

There is another aspect to reduced lung volumes. The aforementioned tendency to breathe at low lung volumes also increases airway resistance with flow limitations¹. Intrinsic positive end-expiratory pressure (PEEPi) is a direct consequence^{1, 3}. PEEPi is the end-expiratory recoil pressure of the respiratory system due to incomplete expiration. This pressure needs to be counteracted by respiratory muscles before flow is achieved adding additional elastic load on the inspiratory muscles and thus adding to the work of breathing. As a side note: A close correlation between PEEPi and BMI has been demonstrated: Pankow et al. showed that the only independent predictor for PEEPi was BMI³.

But PEEPi may also occur without flow limitations when the expiratory time (T_e) is too short for pressure equilibration. Due to changed breathing patterns in obese patients, T_e is considerably shorter compared to non-obese subjects resulting in incomplete exhalation. Other mechanisms – such as post-inspiratory activity of the inspiratory muscles – are leading to persistent diaphragmatic activity after inspiration which may also further influence PEEPi³.

In summary, the lung in obese patients suffers not only from pressure from the chest and the abdomen, but also from intrinsic PEEP

which results in a severely increased work load for the respiratory muscles (work of breathing).

Changed breathing patterns

In order to cope with this increased work of breathing, obese patients show changed breathing patterns. They breathe at higher frequencies and lower tidal volumes in order to reduce muscle load and to avoid hypoventilation¹. Additionally, their much shorter expiration times compared to non-obese patients may also support PEEPi. The combination of low FRC, ERV, and tidal volumes suggests that more obese patients breathe close to closing volume which promotes atelectasis⁶.

Impact of supine posture

The supine position is standard during induction of general anesthesia. This position worsens most of the effects discussed previously. When positioning a patient in the supine posture, lung volumes are further decreased and obese subjects may breathe close to reserve volume. Transdiaphragmatic pressure swings increase significantly and further add to the inspiratory muscle load². The increased chest wall load unleashes its full effect on the respiratory system. Airway resistance and flow limitations increase. Whereas only 2 out of 8 obese patients had flow limitations in the upright position, 7 of 8 patients had flow limitations in the supine position. Thus, PEEPi increases with the adoption of the supine position³. In a study, an average PEEPi of 5.3 cmH₂O was

measured in obese patients in supine posture². Another study was in agreement with this finding and showed that PEEP_i in obese patients increased from 1.4 cmH₂O to 4.1 cmH₂O when changing from upright to supine position³. On average, PEEP_i increases by 0.2 cmH₂O per unit of BMI².

So lower lung volumes, low tidal volumes, and corresponding atelectasis may have significant influence on the volume of oxygen stores that can be filled during pre-oxygenation. The increased work of breathing and the corresponding breathing patterns are likely to negatively influence the success of pre-oxygenation based solely on spontaneous breathing. This can lead to the previously described shorter time to arterial desaturation after onset of apnea. Anticipating more difficult mask ventilation and a longer time for securing the airway, it becomes obvious that pre-oxygenation and induction of obese patients needs to be altered in order to maximize the duration of apnea tolerance.

APPROACHES TO PRE-OXYGENATION AND INDUCTION IN OBESE PATIENTS

Current literature appears to provide sound guidance on how to best pre-oxygenate and induce obese patients to achieve a prolonged time frame of adequate oxygen saturation even for difficult intubation - reducing the incidence of atelectasis and even postoperative pulmonary complications in those patients. The following may be considered during pre-oxygenation and induction of obese patients:

1. Elevate the patient's head and trunk.
2. Apply positive airway pressure during pre-oxygenation – instead of solely relying on spontaneous breathing.
3. Consider the fraction of inspired oxygen during pre-oxygenation and induction.
4. Perform a lung-recruitment maneuver following endotracheal intubation and utilize optimal PEEP during subsequent mechanical ventilation.

Elevating head and trunk during pre-oxygenation and intubation

Optimal positioning of the obese patient is vital during pre-oxygenation and induction of general anesthesia. Abdominal pressures are reduced and the chest wall obviously imposes less weight on the lung improving lung volumes, especially FRC^{1,6}. It has been demonstrated that the duration of apnea without desaturation is longer compared to supine position just by putting the patient into a 25° head-up position⁶. With regards to intubation in this position, conflicting opinions can be found. One article states that the visualization of the glottis is said to be improved during intubation in the lifted position¹. Another recommends balancing the longer duration of apnea without desaturation against a potentially more difficult tracheal intubation and an increased incidence of hypotension at the induction of anesthesia⁶. Others clearly recommend combining the reverse Trendelenburg position with a 25° head-up position to achieve optimal results^{11, 14, 20}.

Beneficial positive airway pressure – with a tight mask

While a head-up position is a first step to relieve the respiratory system, positive airway pressure applied during pre-oxygenation seems to be another promising measure. Various articles recommend the use of positive airway pressure during pre-oxygenation.



A study demonstrated that a CPAP of 7 cmH₂O applied in obese patients in supine posture reduced the PEEP_i on average from 4.1 to 0.8 cmH₂O which is similar to the PEEP_i in non-obese patients when supine. So CPAP is able to offset PEEP_i². Diaphragmatic EMG (EMG_{di}), which is an indicator for diaphragmatic activation and thus for the load on the respiratory system, was found to be significantly reduced by the application of CPAP indicating that CPAP reduces the work of breathing for these patients². CPAP

during pre-oxygenation may also provide a significantly longer tolerance of apnea in obese patients. It was found that in comparison with pre-oxygenation at ambient pressure (ZEEP), the application of 5 cmH₂O of CPAP provides higher arterial oxygenation tension at the end of pre-oxygenation and a longer duration of apnea before desaturation. In this research, the time to SpO₂ < 93 % was increased from 273 seconds without CPAP to 496 seconds with CPAP⁹. Another study demonstrated that a CPAP of 10 cmH₂O during pre-oxygenation and induction caused significantly higher oxygenation (SaO₂ and PaO₂) values and the estimated shunt volume was significantly lower compared to the control group⁷. The use of non-invasive pressure support ventilation (NIV-PSV) was also shown to be beneficial during pre-oxygenation¹¹.

Research also suggests that as the BMI increases the more positive pressure seems to be required to positively influence the effectiveness of pre-oxygenation. Bourouche et al. stated that in morbidly obese patients a CPAP of 7.5 cmH₂O could improve the duration of apnea without desaturation. However, when a CPAP of 5 cmH₂O is combined with PSV of 5 cmH₂O during pre-oxygenation, oxygenation improved and desaturation episodes decreased compared with neutral-pressure breathing¹⁰.



To nevertheless underline the relevance of the 25° head-up position and/or the reversed Trendelenburg position even when using positive pressure for pre-oxygenation: Many authors actually studying positive pressure ventilation also stress the important role posture still has in this scenario.

CPAP, PEEP and PSV

In this respect – depending on the ventilator technology deployed – there may be a notable difference in CPAP and PEEP, especially in spontaneous breathing. PEEP is a residual pressure held in the system by a valve. This means that a spontaneously breathing patient exhales against a resistance which increases work of breathing. Setting PEEP at or above intrinsic PEEP may offset PEEPi and thus reduce work of breathing. If set above PEEPi that may help recruit areas of atelectasis. Most ventilator technologies will not have the capability to sufficiently compensate for leaks and cannot hold the pressure actively. Real CPAP in spontaneous breathing actively holds pressure with the support of the ventilator while allowing for free spontaneous breathing around the set pressure level. To further ease the work of breathing and to help increase lung volumes (and thus oxygen stores), pressure support ventilation supports tidal breathing by actively supporting spontaneous inspirations with a set pressure in a synchronized manner.

Tip: For further technical background information, see our “technology insights” [e-book](#).

Finally, the pressure you apply with CPAP, PEEP and/or PSV needs to actually get to the patient. Don't forget that the masks you use for pre-oxygenation need to be adapted and tightly fitted to the patient. Leaks between the mask and the patient's face may lead to dilution of the fraction of inspired oxygen. About 20 % dilution of oxygen by ambient air occurs if the mask is not tightly applied to the patient's face – even 40 % dilution occurs when it is just held close to the face. Therefore a high quality mask, well fitted to the face of the patient, needs to be securely applied on the face of your patient. Remember that many factors influence the ability to achieve a proper mask seal, including facial hair, type of mask, facial structure, etc¹⁰.

Consider the fraction of inspiratory oxygen during pre-oxygenation and induction

In lean patients, pre-oxygenation is typically performed with 100 % oxygen in order to ensure sufficient oxygen volume in the lung to increase the time to desaturation after the onset of apnea. Experts state that high oxygen concentrations during pre-oxygenation in obese patients may favor atelectasis due to oxygen uptake from

poorly ventilated alveoli even more so morbidly obese patients⁶. Clinicians state that a reduced oxygen fraction may be used to reduce resorption atelectasis in the obese patient population²⁰. However, most authors cited in this article applied high oxygen concentrations during pre-oxygenation and induction of anesthesia in order to ensure a sufficient duration without desaturation after apnea. Rusca et al. state that the amount of atelectasis is larger in obese patients when a high fraction of inspired oxygen is applied and that a lower oxygen fraction prevents atelectasis formation during induction of anesthesia. However, they do not recommend this technique due to the reduced margin of safety when facing a potentially difficult face mask ventilation and/or intubation in obese patients. The same study suggests that the application of positive airway pressure during anesthesia induction can prevent atelectasis formation despite the use of high oxygen concentrations¹⁵.

Lung recruitment after endotracheal intubation

The time between onset of apnea and achieved endotracheal intubation and subsequent ventilation puts the obese patient again at risk of atelectasis formation. Therefore, it is recommended, especially in morbidly obese patients, to perform a recruitment maneuver right after endotracheal intubation followed by the application of PEEP during controlled mechanical ventilation. PEEP alone, without recruitment, appears to be insufficient to reopen

atelectatic lung tissue. However, when positive pressure ventilation was applied before endotracheal intubation, authors estimate that a pressure of 40 cmH₂O would be sufficient while minimizing the potential risk of barotrauma¹². Although PEEP alone is not sufficient to recruit the lung, it is effective in preventing atelectasis formation^{12,17}. PEEP should be titrated on an individual patient basis. Various approaches have been suggested to recruit the closed lung and to titrate PEEP. Chris Thompson provides practical insights into how this can be done²⁰.

Conclusions and Outlook

Obese patients may require more attention by the anesthetist and most certainly require adapted approaches in pre-oxygenation and induction of general anesthesia. However, the above applies to adult patients and does not include pediatric patients. But obesity is not just representing an increasing challenge in adult patients, but also in children. The WHO estimates that approximately 41 million children under 5 years of age were affected by overweight or obesity in 2014. This is an alarming number that should alert anesthetists to reaffirm how to best manage obese children. Therefore, we will elaborate on the implication on the management of general anesthesia in obese children in one of our next articles.

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