An increasing number of obese patients will require anaesthesia. In this article we will outline some of the challenges for anaesthetists in regards to pre-oxygenation and induction of obese patients based on selected literature, explore anatomical and physiological backgrounds relevant to general anaesthesia, and provide an overview of literature-recommended approaches.
Obese Patients impose an increasing challenge on anaesthesia care providers. Not only the sheer number of those patients is increasing, but also the management of obese patients during general anaesthesia 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 anaesthesia 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. You will have seen this in your daily clinical practice. 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 females\(^1\). In Germany, 20.8 % of the entire population is reported to be obese, and 37.4 % present with overweight “only”\(^1\). Even within Chinese population 4-5 % of males and females must be referred to as obese. This includes obesity (BMI >= 30 kg/m\(^2\)) as well as morbid obesity (BMI >= 40 kg/m\(^2\)).

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 meanwhile reach 671 Million people\(^1\). 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 anaesthetists 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 anaesthesia care providers throughout the entire anaesthesia 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 anaesthesia 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 pneumoperitoneum\(^5\).

In anaesthesia, 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 anaesthesia, 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.
Adapted approaches to pre-oxygenation and induction may be needed

Difficult mask ventilation / difficult intubation
Anaesthesia care providers 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 anaesthesia, 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 death\textsuperscript{11}. 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\textsuperscript{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 apnoea has to be overcome in the obese patient.

Fast desaturation / more atelectasis
Obese patients may desaturate faster. Even with pre-oxygenation, the time of apnoea to clinically relevant arterial oxygen desaturation is anticipated to be significantly shorter compared to normal weight patients\textsuperscript{11}. Tanoubi et al. stated that – in obese patients – desaturation can occur 1-2 minutes after apnoea begins or within the time for a single attempt of laryngoscopy and tracheal intubation\textsuperscript{6}. Even in 85-90 % of healthy non-obese patients atelectasis occurs within minutes after induction of anaesthesia: A portion of 15 % of the lung will be atelectatic, in turn resulting in a shunt volume of approx. 5-10 %. In obese patients, the area of anaesthesia induced atelectasis is much larger compared to lean patients\textsuperscript{5}. 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 anaesthesia and the postoperative phase when running standard induction and ventilation regimen\textsuperscript{5}. 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 could think. In a sample of 1,050 healthy patients, inadequate pre-oxygenation \((\text{FeO}_2 < 90 \text{ %})\) 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 apnoea tolerance\textsuperscript{10}.

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 present in obese patients.
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 ventilation\(^1\). 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 pressures\(^1\).

b) Increased abdominal volume and visceral fat lead to diaphragm elevation and increased diaphragmatic impedance\(^1\). This reduces the efficacy of the diaphragm to about half of that in non-obese patients\(^2\). 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 position\(^3\).

c) Blood volume may be increased by up to 50% in obese patients in order to cope with the increased oxygen consumption\(^1\). Almost 50% of obese patients suffer from hypertension which also affects pulmonary circulation\(^4\).

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 +/- study demonstrated that – after induction of anaesthesia (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 anaesthesia 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 present with pre-existing atelectasis in the awake and upright position\(^5\). In addition to that, the anaesthesia-induced area of atelectasis is much larger in obese patients compared to lean patients\(^7\). 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 apnoea without desaturation\(^6\). As well, negative effects of low end-
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 consequence¹ 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 (Te) is too short for pressure equilibration. Due to changed breathing patterns in obese patients, Te 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 anaesthesia. 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 position⁸. In
a study, an average PEEPi of 5.3 cmH\textsubscript{2}O was measured in obese patients in supine posture\textsuperscript{2}. Another study was in agreement with this finding and showed that PEEPi in obese patients increased from 1.4 cmH\textsubscript{2}O to 4.1 cmH\textsubscript{2}O when changing from upright to supine position\textsuperscript{3}. On average, PEEPi increases by 0.2 cmH\textsubscript{2}O per unit of BMI\textsuperscript{2}.

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 apnoea. 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 apnoea tolerance.

**Elevating head and trunk during pre-oxygenation and intubation**

Optimal positioning of the obese patient is vital during pre-oxygenation and induction of general anaesthesia. Abdominal pressures are reduced and the chest wall obviously imposes less weight on the lung improving lung volumes, especially FRC\textsuperscript{1,6}. It has been demonstrated that the duration of apnoea without desaturation is longer compared to supine position just by putting the patient into a 25\textdegree head-up position\textsuperscript{6}. 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 position\textsuperscript{1}. Another recommends balancing the longer duration of apnoea without desaturation against a potentially more difficult tracheal intubation and an increased incidence of hypotension at the induction of anaesthesia\textsuperscript{6}. Others clearly recommend combining the reverse Trendelenburg position with a 25\textdegree head-up position to achieve optimal results\textsuperscript{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 cmH\textsubscript{2}O applied in obese patients in supine posture reduced the PEEPi on average from 4.1 to 0.8 cmH\textsubscript{2}O which is similar to the PEEPi in non-obese patients when supine. So CPAP is able to offset PEEPi\textsuperscript{2}. Diaphragmatic EMG (EMG\textsubscript{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 patients\textsuperscript{2}. CPAP during pre-oxygenation may also provide a significantly longer tol-
EFFECTIVE PRE-OXYGENATION AND INDUCTION 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 apnoea before desaturation. In this research, the time to SpO₂ < 93 % was increased from 273 seconds without CPAP to 496 seconds with CPAP. 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 group. The use of non-invasive pressure support ventilation (NIV-PSV) was also shown to be beneficial during pre-oxygenation.

Research also suggests that as the BMI increases the more positive pressure seems to be required to positively influence the effectiveness of pre-oxygenation. Bouroche et al. stated that in morbidly obese patients a CPAP of 7.5 cmH₂O could improve the duration of apnoea 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 breathing.

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, etc.

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 apnoea. Experts state that high oxygen concentrations during pre-oxygenation in obese patients may favour atelectasis due to oxygen uptake from poorly ventilated alveoli even more so morbidity obese patients.
Clinicians state that a reduced oxygen fraction may be used to reduce resorption atelectasis in the obese patient population\(^20\). However, most authors cited in this article applied high oxygen concentrations during pre-oxygenation and induction of anaesthesia in order to ensure a sufficient duration without desaturation after apnoea. 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 anaesthesia. 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 anaesthesia induction can prevent atelectasis formation despite the use of high oxygen concentrations\(^15\).

**Lung recruitment after endotracheal intubation**
The time between onset of apnoea 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 manoeuvre 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 mmH\(_2\)O would be sufficient while minimizing the potential risk of barotrauma\(^12\). 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 done\(^20\).

**Conclusions and Outlook**
The obese patients may require more attention by the anaesthetist and most certainly require adapted approaches in pre-oxygenation and induction of general anaesthesia. However, the above applies to adult patients and does not include paediatric 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 anaesthetists to get trained on managing the obese child. Therefore, we will elaborate on the implication on the management of general anaesthesia in the obese child in one of our next articles. We keep you posted...

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