Perioperative lung protection for obese patients

Effective Pre-oxygenation and Induction in Obese Patients

Increasing numbers of obese patients are undergoing surgery, presenting a new set of challenges for anaesthesia providers. This first of two articles will outline some of the challenges that anaesthetists are faced with when dealing with these patients, focussing on pre-oxygenation and the induction of anaesthesia. Based on selected current literature, the article will explore the anatomical and physiological issues of morbid obesity relevant to general anaesthesia, and discuss the strategies available to safely and best manage these cases.

Obese patients impose an increasing challenge on anaesthesia care providers. Whilst the total numbers of patients with obesity is increasing, there are also many more patients with extreme levels of obesity, in whom the management of general anaesthesia may require different approaches compared to non-obese patients. Potentially hazardous situations may occur if these patients are not appropriately treated.

Obese patients crease more challenges for anaesthesia care providers

The global incidences of Obesity (BMI >30kg/m^2) and Morbid Obesity (BMI >40kg/m^2) are a consequence of worldwide adaptation of Western diet, lifestyles and behaviour – and the incidences continue to rise. The results of this obesity epidemic are clearly visible in daily clinical practice, and in many parts of the world, this is producing a major challenge for healthcare providers.

According to the World Health Organization (WHO), in 2016, more than 1.9 billion adults were overweight, and of these, over 650 million were obese. In the same year, 41 million children under five years of age, and over 340 million five- to 19-year-olds were overweight or obese. A recent report shows a prevalence of obesity of 32 % in males and 34 % in females in the US , while in the UK, 25 % of males and females are obese.[2] In Germany, 21 % of the entire population is obese, and 37 % present as overweight , with numbers continuing to rise. The most concerning aspect is that the greatest increases in levels of obesity are occurring in the pediatric populations. This has an additional impact, as the specific co-morbidities related to obesity (diabetes, pulmonary and systemic hypertension, heart failure and atrial fibrillation) all tend to develop over years or even decades; and thus these co-morbidities are likely to be have progressed and be more severe when morbid obesity has developed in the teens, rather than in adulthood.

Why are obese patients a challenge?

Apart from pure weight, which makes the general handling and the preparation for surgery more difficult, there are a number of specific issues in the morbidly obese patient that impose specific challenges and increase the risk of severe perioperative complications.

Apnoeic Desaturation

Anatomical and physiological changes put obese patients at high risk for developing early hypoxemia during anaesthesia induction, because of an imbalance between oxygen supply and oxygen demand. There is a reduced supply because of reduced oxygen stores associated with a reduced functional residual capacity[4]. There is an increased demand because of the increased basal metabolic rate and thus oxygen requirement.[5] This imbalance is of particular importance at induction, because during any period of apnoea – particularly whilst trying to establish a secure airway – arterial desaturation will be rapid and may be profound.

Specific approaches (described below) are used to increase the oxygen stores and thus attempt to extend the period before, and to slow the rate at which desaturation occurs. The terms "Safe Apnoea Period" (SAP) and "Duration of Apnoea Without Desaturation" (DAWD) are both used to describe the length of time before significant and potentially harmful levels of hypoxemia are reached.

The same anatomical and physiological changes leading to low lung volumes also increase the tendency to intra-operative and post-operative atelectatic collapse and hence the risk of postoperative pulmonary complications.[6] This tendency to collapse may be worsened by aspects of the surgical intervention itself, e.g. the use of laparoscopic techniques with a pneumoperitoneum utilizing high intra-abdominal pressures, and steep head-down positions, which further impact upon lung mechanics.[7]

Not all obese patients are affected to the same degree, and there is a spectrum of lower and higher-risk patients at any level of BMI. In modest levels of obesity, these changes are not particularly marked, and in patients with the peripheral fat distribution more usually seen in females (where fat is predominantly external and deposited on the arms, thighs and buttocks), respiratory changes are not great. But in those patients with the typical male pattern of central obesity, with predominantly intra-abdominal fat deposition, the changes described above can be very significant. This intra-abdominal fat is also the metabolically active fat that releases cytokines associated with the inflammatory and pro-thrombotic processes of the metabolic syndrome, triggering diabetic and hypertensive disorders. Patients with central adiposity – described often as "apple-shaped" – are

at highest risk of these co-morbidities, and after many years of morbid obesity, hypertension and diabetes, cardiovascular reserve is diminished and these patients are particularly vulnerable to peri-operative complications.
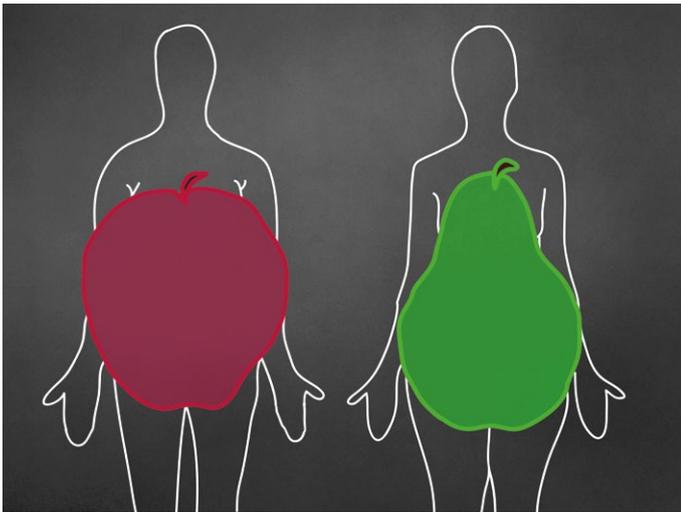
Fat distribution is an important consideration in anaesthesia care: apples vs. pears

Adapted approaches to pre-oxygenation and induction may be needed

Difficult mask ventilation / difficult intubation

Anaesthesia care providers need to anticipate that induction and securing the airway is likely to take longer in any obese patient. Obesity and morbid obesity are frequently associated with difficult mask ventilation and, to a degree, with difficult intubation. In particular, the problems of bag-mask ventilation seem to be frequently underestimated.

In a series of 50,000 patients from a single US institution, BMI was a highly significantly association with impossible bag-mask ventilation.[8] Subsequent studies in an even larger cohort confirmed that a BMI of > 35 was an independent predictor for difficult mask ventilation combined with difficult laryngoscopy, with an odds ratio of > 2.

The evidence for difficult intubation in the obese is less clear, with multiple studies showing conflicting results. From analyses of the Danish national database[9], it would appear that the incidence of difficult intubation in the obese is increased by some 20 to 30 %.

A recent single centre study suggested that a BMI >30kg/m^2 was associated with a lower rate of successful intubation at the first attempt, but that higher BMI did not predict greater difficulty.[10]

However, in the event of airway difficulties developing, the risk of serious complications in morbidly obese patients is reported to be four times higher than that of lean patients. In a retrospective review of major complications of airway management in the UK (NAP4), 25 % of 77 obese patients, for whom airway management complications were reported, suffered permanent brain damage or death.[11]

What is clear is that whilst the overall incidence of intubation difficulty in the obese patient may not be much increased, on those occasions when problems with the airway do arise, oxygen saturations fall far faster, and time is not on the anaesthetist's side. Therefore techniques that will extend the safe apnoea period before desaturation should be routine and known to all those who manage anaesthesia in this patient group. The tips and tricks to achieve the best possible pre-oxygenation with the highest possible oxygen stores during the induction period should be familiar to all anaesthesiologists.
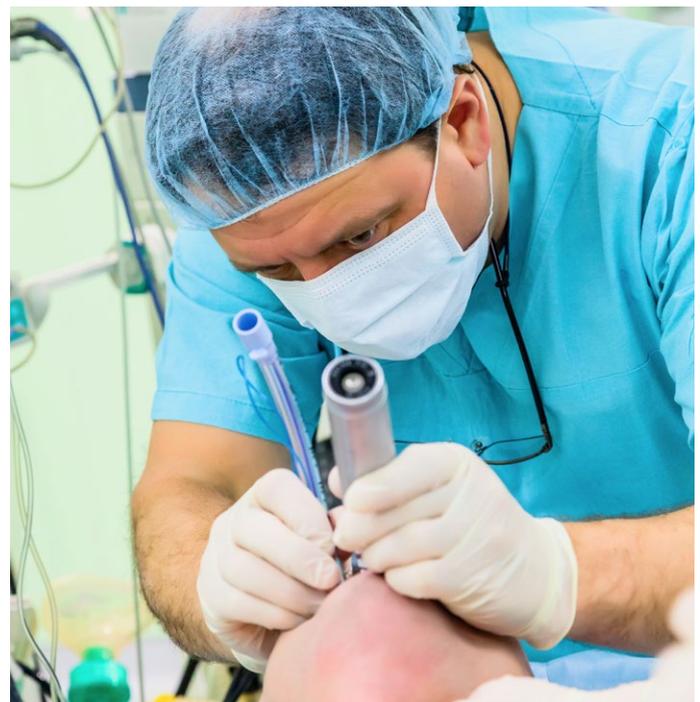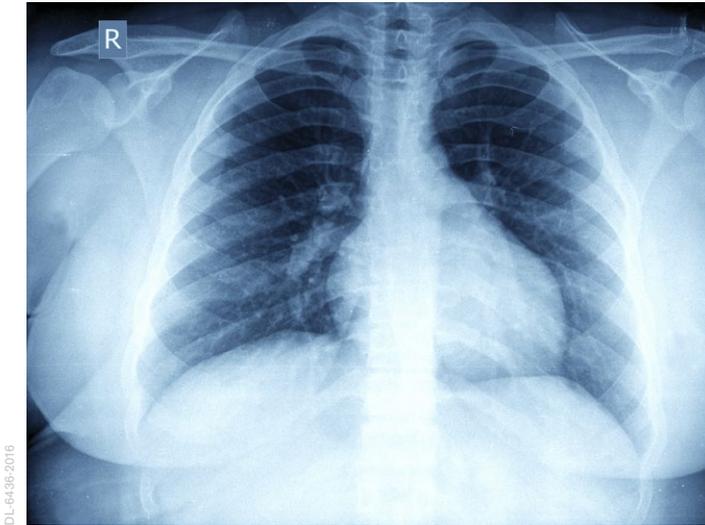
Chest x-rays of an obese patient (left) with an elevated diaphragm and a normal weightpatient (right) with a normal diaphragm position.

Regurgitation Risk

The obese patient empties their stomach at the same rate as the non-obese patient, and this has been elegantly demonstrated with recent MRI studies.[12] In elective surgery, the incidences of reflux in the asymptomatic obese patient are not demonstrably different from the non-obese, and anaesthetists who have a regular bariatric surgery practice will not use rapid sequence inductions as a routine. Absolute residual volumes of gastric fluid may be somewhat higher than in the non-obese, but when adjusted for patient size, the difference is negligible. There is one clinical scenario where additional caution is required, and that is when bariatric surgery has occurred and a gastric band is in place.

Lap Band Surgery
— esophagus
— gastric band
stomach pouch —
stomach —
duodenum —
— port (under skin)

There is uncertainty as to whether deflating a gastric band is always necessary, but if the patient has symptomatic acid reflux there is a considerable chance that the band has slipped. In this situation, there is frequently a larger volume residue above the band that can rapidly reflux, and the patient should be treated as having a full stomach and all appropriate precautions followed.

Reasons for decreased oxygen stores and increased work of breathing

Obesity leads to a decreased respiratory system compliance. Compliance is seen as the stiffness of the respiratory system, impacting upon spontaneous breathing as well as mechanical ventilation. The following anatomical changes mainly contribute to this:

a) Increased mass loading of fat on the chest wall, pushing down from above, particularly in the supine position, leading to high pleural pressures.

b) Increased abdominal fat deposition, both subcutaneous, but particularly intra-abdominal i.e. visceral fat, will lead to elevation of the diaphragm pushing up from below, and additionally impede diaphragmatic movement. This may reduce the mechanical efficiency of the diaphragm significantly, compared to the non-obese patient.

c) Because of elevation and a partial splinting of the diaphragm, in order to maintain minute ventilation in the supine position, chest movement tends to be more anterior-posterior, with
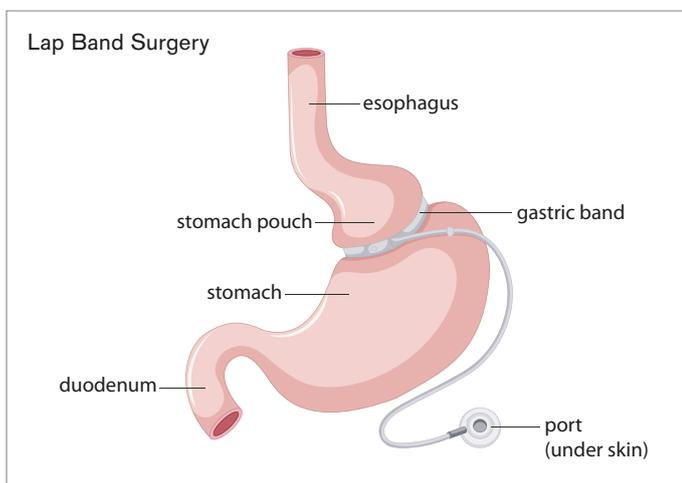
reduced ventilation of the poster-basal segments. This impacts upon both matching of ventilation to perfusion, and may also result in atelectatic collapse over time; both of these contribute to the baseline arterial hypoxaemia frequently seen in these patients. The reduced lung volumes secondary to collapse will further affect overall lung compliance.

d) Finally, cephalad movement of the diaphragm in the supine position results in an overall shortening of the mediastinum, with the carina moving upward and the tension on the trachea and larynx being reduced. This has been suggested to be a contributory factor in airway collapse in Obstructive Sleep Apnoea in the non-anaesthetised patient. It is certainly a cause of endobronchial intubation and/or carinal irritation and bronchospasm, especially if further cephalad movement of the diaphragm and mediastinum occurs. This typically occurs as a result of the surgeon creating a pneumoperitoneum. Note: Arterial desaturation, coughing or degrees of bronchospasm developing just after the start of surgery should immediately lead to a check of the length of the endotracheal tube at the teeth and examination, to exclude this surprisingly common event.

Implications of reduced lung volumes for obese patients

Reduced lung volumes, specifically a reduced Functional Residual Capacity and a reduced Expiratory Reserve Volume, means that breathing occurs overall at lower lung volumes. This predisposes to collapse and closure of small airway and air trapping, making obese patients more prone to the formation of atelectasis. As indicated above, morbidly obese patients will frequently have a degree of pre-existing atelectasis in the awake and upright position. In addition to that, anaesthesia-induced atelectasis will be much greater in obese patients compared to lean patients.

The reduced FRC can mislead the clinician when assessing adequacy of pre-oxygenation. During pre-oxygenation, it will appear that wash-in is faster in patients with a reduced FRC, i.e. the targeted expiratory oxygen fraction is achieved quickly. This is a false re-assurance, as there are reduced oxygen stores in the volume-reduced lung that will in turn result in a shortened duration of apnoea without desaturation.
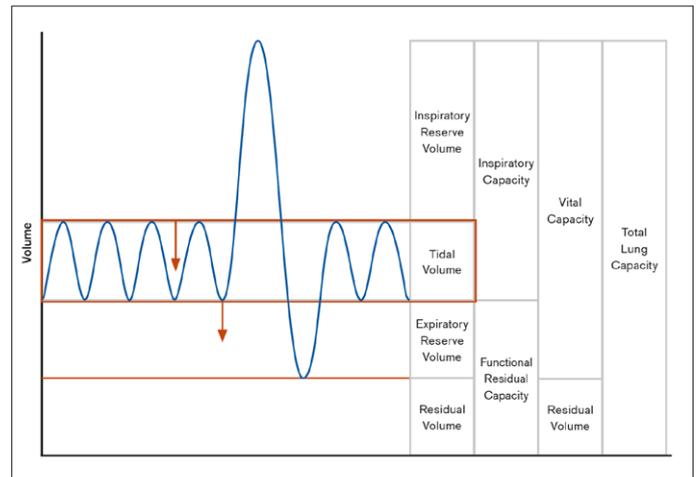
Reduction in FRC is mainly caused by a reduction of expiratory reserve volume. The tidal volume is reduced to breathe more economic but respiratory rate is faster to ensure sufficient ventilation.

Impact of Posture during Induction

Appropriate head-up posture is vital during induction in the obese. The supine position allows the anaesthetist to easily reach over to intubate the obese patient, and thus is the historical standard during induction of general anaesthesia. However, in the obese it is the enemy of optimal pre-oxygenation. When positioning a patient in the supine posture, lung volumes are further decreased, atelectasis is increased and obese subjects may breathe close to reserve volume. Some patients are unable to breathe adequately when lying supine, and in the extreme case, if forced into that position, may develop an acute pulmonary hypertensive crisis and decompensate cardiovascularly. This was first reported more than 40 years ago as the "Obesity Supine Death Syndrome".[13] Whilst these are extremely rare events, any patient who reports sleeping in a chair should be considered at high risk of acute respiratory decompensation. These patients should not be laid flat, and pre-operative assessment of the morbidly obese should include this question.

Although the majority of obese patients are able to lie flat (although most of these will sleep on their side rather than supine), the combination of lower lung volumes, low tidal volumes, and baseline atelectasis may all contribute to a reduction in the total lung oxygen storage that can be achieved during pre-oxygenation. This can lead to the previously described shorter time to arterial desaturation after onset of apnoea.

Elevating head and trunk during pre-oxygenation

The more vertical the upper body of the patient, the more the abdominal pressures are reduced as the abdominal contents fall away and their weight is supported on the pelvic brim. Additionally, fat on the chest wall imposes less weight on the lung, thus improving lung volumes, especially FRC. 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° head-up position.[14] With regards to intubation in this position, conflicting opinions can be found. It makes sense that visualization of the glottis is improved during intubation in the lifted position, but the operator needs to be able to stand over the patient's head, either by standing on a step or platform, or by having an operating theatre table that can be taken very low down towards the ground. The second problem with the head up position is an increased incidence of hypotension at the induction of anaesthesia, particularly if inducing the patient whilst using a degree of CPAP (see below). In any individual patient, these factors must be weighed up. However, amongst those that regularly provide anaesthesia for bariatric surgery, the consensus is that a head up tilt of around 20-30 degrees is best practice. It also markedly reduces the risk of passive reflux and regurgitation.

Pre-oxygenation with positive airway pressure

While a head-up position is the primary step to improve the respiratory mechanics and improve lung volumes, CPAP or some other variation of positive airway pressure applied during pre-oxygenation will further increase these lung volumes, and extend the duration of apnoea without desaturation. This is achieved through two processes: Firstly, it will further increase the Functional Residual Capacity. Secondly, if used in conjunction with forced vital capacity breaths, it will tend to re-open and hold open any atelectatic segments that may have developed in the bases, which in turn will reduce shunt and mismatch, and thus increase baseline arterial oxygen saturations.[15]

The level of CPAP required, and what patients can comfortably tolerate, varies between individuals. Morbidly obese patients with diagnosed Obstructive Sleep Apnoea are often on CPAP therapy with levels of 16 or even 18 cmH$_2$O, and these patients will easily tolerate CPAP at this level; but for moderately obese patients who do not have CPAP therapy at home, such high levels are unfamiliar, feel uncomfortable and are probably not required.

In daily practice, providing the patient does not have a phobia of face-masks, a moderately tightly applied mask with CPAP levels set at between 6-10 cmH$_2$O will both improve the effectiveness of pre-oxygenation, but very importantly will also have the benefit of splinting open the upper airway as induction takes place and muscle relaxation occurs. This will reduce the incidence of collapse and obstruction of the upper airway, and thus reduce the need to remove the facemask to insert airway adjuncts, losing the CPAP effect.

Whilst there are theoretical concerns, insufflation of the stomach does not happen at these levels of CPAP, and provided peak inspiratory pressures during face-mask ventilation are kept modest i.e. below around 20cmH$_2$O, gastric distension should not occur at all.

It is obvious that all these benefits of CPAP cease when the facemask is removed for intubation, at which point the lungs will recoil to the reduced FRC and atelectasis will begin to develop. This underlines the relevance of the 25° head-up position. Most authors studying positive pressure ventilation and induction in the obese also stress the vital role posture has in this scenario.

CPAP, PEEP and Pressure Support Ventilation

Pre-oxygenation using CPAP can be achieved manually or mechanically. 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 that increases work of breathing. Ideally, to reduce work of breathing and maximise inspiratory volumes, active CPAP or even a low level of Pressure Support Ventilation should be administered to these patients. 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 reduce the work of breathing and to help increase lung volumes (and thus oxygen stores), pressure support ventilation can be utilized during pre-oxygenation. This supports tidal breathing by actively supporting spontaneous inspirations with a set pressure in a synchronized manner.

Tip: For further technical background information, see the "technology insights" Link

Finally, the pressures that are set up with CPAP, PEEP and/or PSV need to actually get to the patient. Masks used during pre-oxygenation need to be reasonably tightly fitting to the patient, as leaks between the mask and the patient's face may not only lead to pressure loss but also cause dilution of the fraction of inspired oxygen. Many factors influence the ability to achieve a proper mask seal, including facial hair. Note: In addition to causing problems with facemask ventilation, beards should be viewed as a red flag in airway assessments – they often hide an underlying small and receding jaw, with all the associated airway difficulties that are associated.

Inspiratory oxygen fraction during pre-oxygenation

High oxygen concentrations in the lung theoretically result in an increased risk of absorption atelectasis, and in the morbidly obese patient with a predisposition to atelectatic collapse this would be even more likely. Some have suggested that a proportion of nitrogen in the gas mixture with a commensurate reduced oxygen fraction may be used to reduce resorption atelectasis in the obese patient population.

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. Even after several minutes of pre-oxygenation, the alveolar gas will still contain water vapour, nitrogen and carbon dioxide, and the alveolar oxygen fraction will never exceed 90 %. Practically and on a balance of risk, it appears that the consensus is to use maximal oxygen concentrations at pre-oxygenation, then after induction and intubation, to perform a simple recruitment manoeuvre followed by adequate positive airway pressure (described below).

High Flow Nasal Oxygen Devices

Recently a variety of devices have been investigated which provide high flows of warmed and humidified oxygen during the phase of pre-oxygenation and intubation. High Flow Nasal Oxygen (HFNO) delivered at rates of 60-70l/min via wide-bore soft nasal cannula, will wash out CO_2 and nitrogen from the supraglottic dead space and provide modest levels of CPAP, in the order of 4-6 cmH$_2$O. These devices can be used to effectively pre-oxygenate the patient, i.e. to fill the alveoli with 90 % oxygen. If they are maintained in place following induction, then the low level of CPAP can maintain the FRC to a significant volume, rather than losing the entire benefit of pre-induction CPAP that occurs when facemask CPAP is removed for airway instrumentation. Furthermore, the low levels of CPAP provided by these high flow rates can reduce the tendency to airway collapse and upper airway obstruction, although this benefit may not be great.

Provided that the airway is patent, through a passive mass flow from nasopharynx into lung, oxygen that is taken up by the bloodstream can be replaced. In the non-obese patient this apnoeic ventilation can prevent desaturation for periods in excess of 40 minutes, although CO_2 clearance becomes an issue.[16] There is relatively little data yet on the effectiveness of these techniques in the obese patient, in terms of maintaining oxygen saturation post-induction, compared to other approaches. One early study looking 90 seconds post induction did demonstrate arterial blood gas oxygenation partial pressures that were significantly better following High Flow Nasal Oxygenation than any other pre-oxygenation modality, but the difference was not huge.[17] More studies will clarify the role of this therapy, but the combination of head up posture and High Flow Nasal Oxygen shows great promise and may well turn out to be the most effective adjunct to preventing desaturation during attempts at intubation.

Lung recruitment after endotracheal intubation

Regardless of the support given during pre-oxygenation and beyond, the time from induction until achieving endotracheal intubation and initiation of ventilation is frequently long enough for a degree of atelectasis formation. It is therefore recommended to perform a recruitment manoeuvre shortly after endotracheal intubation, followed by the application of PEEP throughout the subsequent period of ventilation. PEEP alone, without recruitment, will be insufficient to re-open atelectatic lung tissue, although it is effective in preventing atelectasis formation.[18] 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].

If laparoscopic surgery is to be performed, this manoeuvre should ideally be performed before insufflation of the peritoneum. Once the pneumoperitoneum is established, recruitment manoeuvres may require even greater plateau pressures, at a level in excess of 45 cmH_2O. In order to prevent the re-occurrence of any atelectasis, PEEP levels may need to be in excess of 15cmH_2O.[19] These pressures will frequently have a significant impact on haemodynamic parameters, and in order to tolerate such manoeuvres, fluid loading and vasopressors may be required. In order to avoid a significant cardiovascular impact, rather than trying to recruit the total lung volume using such high pressures, an increased inspired oxygen and a degree of atelectasis may be tolerated, which has been termed permissive atelectasis. As always, a balance must be found in the individual patient, causing the least possible harm.

Conclusions and Outlook

The obese patient requires careful management by the anaesthetist, and because of the rapidity of desaturation, if airway problems do arise the situation can deteriorate very quickly. Safe practice certainly requires adapted approaches in pre-oxygenation and induction of general anaesthesia as outlined above. But obesity does not just represent an increasing challenge in adult patients, but also in children. The WHO estimates that approximately 41 million children under five years of age were affected by over-weight or obesity in 2014. Although obesity in the young is perhaps less of an anaesthetic issue, childhood obesity is a demographic time bomb. The impact this will have in the future is immense and every anaesthetist will increasingly face morbidly obese patients and needs to know their optimal perioperative management. Watch this space!

Discover more on our website www.draeger.com/protective-ventilation

REFERENCE:

1. www.WHO.int/en/news-room/fact-sheet/detail/obesity-and-overweight accessed 1/8/18

2. Hodgson LE, Murphy PB, Hart N. Respiratory management of the obese patient undergoing surgery. J Thorac Dis. 2015 May;7(5):943-52.

3. Deutsche Adipositas Gesellschaft, Die Prävalenz von Übergewicht und Adipositas in Deutschland, URL: http://www.adipositas-gesellschaft.de/; viewed 14.05.2016

4. Pelosi, P., Croci, M., Ravagnan, I., Tredici, S., Pedoto, A., Lissoni, A., & Gattinoni, L. (1998). The effects of body mass on lung volumes, respiratory mechanics, and gas exchange during general anesthesia. Anesthesia and Analgesia, 87(3), 654–660.

5. Kress, J. P., Pohlman, A. S., Alverdy, J., & Hall, J. B. (1999). The impact of morbid obesity on oxygen cost of breathing (VO(2RESP)) at rest. American Journal of Respiratory and Critical Care Medicine, 160(3), 883–886.

6. Salome CM, King GG, Berend N. Physiology of obesity and effects on lung function. J Appl Physiol. 2010 Jan;108(1):206-11.

7. Sprung, J., Whalley, D. G., Falcone, T., Warner, D. O., Hubmayr, R. D., & Hammel, J. (2002). The impact of morbid obesity, pneumoperitoneum, and posture on respiratory system mechanics and oxygenation during laparoscopy. Anesthesia and Analgesia, 94(5), 1345–1350.

8. Kheterpal, S., Healy, D., Aziz, M. F., Shanks, A. M., Freundlich, R. E., Linton, F., et al. (2013). Incidence, predictors, and outcome of difficult mask ventilation combined with difficult laryngoscopy: a report from the multicenter perioperative outcomes group. Anesthesiology, 119(6), 1360–1369.

9. Lundstrøm, L. H., Møller, A. M., Rosenstock, C., Astrup, G., & Wetterslev, J. (2009). High body mass index is a weak predictor for difficult and failed tracheal intubation: a cohort study of 91,332 consecutive patients scheduled for direct laryngoscopy registered in the Danish Anesthesia Database. Anesthesiology, 110(2), 266–274.

10. Saasouh, W., Laffey, K., Turan, A., Avitsian, R., Zura, A., You, J., et al. (2018). Degree of obesity is not associated with more than one intubation attempt: a large centre experience. British Journal of Anaesthesia, 120(5), 1110–1116.

11. Cook, T. M., Woodall, N., Frerk, C., Fourth National Audit Project. (2011). Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. British Journal of Anaesthesia, 106(5), 617–631.

12. Shiraishi, T., Kurosaki, D., Nakamura, M., Yazaki, T., Kobinata, S., Seki, Y., et al. (2017). Gastric Fluid Volume Change After Oral Rehydration Solution Intake in Morbidly Obese and Normal Controls. Anesthesia and Analgesia, 124(4), 1174–1178.

13. Tsueda K; Debrand M; Zeok SS; Wright BD; Griffin WO. (1979) Obesity Supine Death Syndrome: Reports of Two Morbidly Obese Patients. Anesthesia & Analgesia. 58(4):345–347

14. Altermatt, F. R., Muñoz, H. R., Delfino, A. E., & Cortínez, L. I. (2005). Pre-oxygenation in the obese patient: effects of position on tolerance to apnoea. British Journal of Anaesthesia, 95(5), 706–709.

15. Gander, S., Frascarolo, P., Suter, M., Spahn, D. R., & Magnusson, L. (2005). Positive end-expiratory pressure during induction of general anesthesia increases duration of nonhypoxic apnea in morbidly obese patients. Anesthesia and Analgesia, 100(2), 580–584.

16. Patel, A., & Nouraei, S. A. R. (2015). Transnasal Humidified Rapid-Insufflation Ventilatory Exchange (THRIVE): a physiological method of increasing apnoea time in patients with difficult airways. Anaesthesia, 70(3), 323–329.

17. Heinrich, S. (2014). Benefits of Heated and Humidified High Flow Nasal Oxygen for Preoxygenation in Morbidly Obese Patients Undergoing Bariatric Surgery: A Randomized Controlled Study. Journal of Obesity and Bariatrics, 1(1), 1–7.

18. Futier, E., Constantin, J.-M., Pelosi, P., Chanques, G., Massone, A., Petit, A., et al. (2011). Noninvasive ventilation and alveolar recruitment maneuver improve respiratory function during and after intubation of morbidly obese patients: a randomized controlled study. Anesthesiology, 114(6), 1354–1363.

19. Tusman, G., Groisman, I., Fiolo, F. E., Scandurra, A., Arca, J. M., Krumrick, G., et al. (2014). Noninvasive Monitoring of Lung Recruitment Maneuvers in Morbidly Obese Patients. Anesthesia and Analgesia, 118(1), 137–144.