Morbid obesity has many consequences for the respiratory system. Excess body fat under the diaphragm, around the ribs, and intra-abdominally reduces chest wall compliance. Lung compliance is also decreased due to an elevated pulmonary blood volume. This decreases the functional residual capacity (FRC) below the closing volume in the dependent portions of the lungs causing airway closure and atelectasis. Most other respiratory function tests are also reduced in morbid obese patients. Metabolism is increased with a higher carbon dioxide production. This induces an increase in cardiac output but not enough for the increased tissue mass and a 15% increase in minute volume ventilation. However, mechanical hyperventilation should be avoided to protect the lungs. Permissive hypercapnia further increases the cardiac output and the tissue oxygenation.

A pneumoperitoneum with carbon dioxide and the Trendelenburg or reverse Trendelenburg position that is used in lower or upper abdominal laparoscopy might lead to further cardiorespiratory compromise in obese patients. Sprung anaesthetised morbidly obese patients and normal control subjects in the supine, Trendelenburg and reverse Trendelenburg positions before and after a pneumoperitoneum with carbon dioxide. Total lung compliance was 30% lower and inspiratory resistance was 68% higher in morbidly obese patients. Pneumoperitoneum further reduced compliance in obese patients. Interestingly, pulmonary artery oxygen tensions were adversely affected only by increases in body weight and did not change significantly after insufflation or repositioning of the patient into the Trendelenburg position. Sprung concluded that the largest detrimental effects on respiratory mechanics are attributable to obesity and supine positioning. The beach chair position or reverse Trendelenburg position is therefore something we should select in morbid obese patients at least during induction and weaning, and if possible during surgery. Morbid obesity and general anaesthesia favour airway closure and lung atelectasis in dependent lung regions, giving a mismatch between ventilation and perfusion. Soderberg demonstrated intrapulmonary shunting of 10% to 25% in morbid obese patients compared with 2% to 5% in normal weight control subjects. Until now continuous peri-operative positive end-expiratory pressure (PEEP) after utilisation of a lung recruitment manoeuvre (LRM) has been the only method to improve this.

Induction of anaesthesia should start with a continuous positive airway pressure (CPAP) mask followed by manual or mechanical assistance with PEEP using a value of between 8 and 15 cmH₂O. When atelectasis occurs only a LRM followed by PEEP can reopen the lungs. We should anticipate this each time PEEP is discontinued or when the endotracheal tube (ETT) is disconnected. Atelectasis will certainly result from ETT suctioning, even if this is correctly performed with a suction catheter diameter half the diameter of the ETT. Closed suctioning with peep during pressure controlled ventilation (PCV) on an anaesthetic machine ventilator and certainly during volume controlled ventilation (VCV) on every ventilator will not maintain lung opening as the fresh gas flow cannot maintain a positive pressure inside the trachea. Only high flow Boussignac PEEP is able to generate high flows sufficient to maintain the level of PEEP during suctioning thus mirroring the capability of intensive care ventilators in PCV mode to do this. It is only then that there is no risk of atelectasis or silent aspiration due to cuff deformation.
Higher values of PEEP are not required during pneumoperitoneum except in morbidly obese patients with an apple shaped body composition. During abdominal inflation, abdominal wall expansion is limited in these patients and only the diaphragm will move. The diaphragm is displaced upwards for which very high values of PEEP are needed to compensate. At an intra abdominal pressure of 15 mmHg a PEEP pressure of more than 21 cmH₂O would be needed to achieve equilibrium. In non-apple shaped abdomens insufflation expands the abdominal girth and forces the thorax more anteriorly thus stretching the dome shaped diaphragm down. No extra PEEP is required to keep the lungs open during a pneumoperitoneum but PEEP should be continued postoperatively in obese patients with obstructive sleep apnoea syndrome (OSAS). The same positive effect is seen with the use of postoperative non-invasive ventilation.

Creation of a pneumoperitoneum increases the inspiratory resistance and requires more carbon dioxide elimination through higher minute volume ventilation. Oxygenation is not affected by pneumoperitoneum but is improved by reverse Trendelenburg position. Less favourable respiratory mechanics in obese patients who undergo laparoscopy may have little impact on overall outcome. Non-apple shaped obese patients tolerate the induction of anaesthesia and supine positioning and are likely to tolerate a pneumoperitoneum and the Trendelenburg position as well.

The LRM manoeuvre is not yet standardized for obese patients and the 40/40 settings used for patients with adult respiratory distress (ARDS) on the intensive care unit (ICU) are too high and can lead to volutrauma. Due to excess intrathoracic fat the lungs of obese patients are smaller. After bariatric surgery that achieves rapid weight loss, previously morbid obese patients might have a ‘baby lung’ syndrome with an increased risk for pneumothorax during LRM and volutrauma.

The use of a LRM creates higher airway pressures or longer inflation times to allow atelectatic alveoli and those with a slower time constant to fill with gas. Several LRM modes have been suggested from ventilation with an increased PEEP or an increased airway pressure. The basic manual LRM mode is delivered as a prolonged manual inflation of 10 seconds or more duration with the APL valve set at 30 or 40 cmH₂O. This mode is not routinely available on anaesthetic ventilators. Some newer ventilators allow the programming of a minimum of 3 cycles with a maximum insufflation time of 10 seconds at a constant pressure of 30 or 40 cm H₂O. Observation of the inspiratory flow will allow the anaesthesiologist to confirm that this flow will not immediately return to zero in the first cycle. This indicates that active recruitment is taking place during inspiration. In the following cycle the inflow becomes shorter as the lung is reopened, unless an airway leak keeps the inspiratory flow constant.

FRC will increase but its measurement is not simple. Static compliance measurements are easier to determine and will show an immediate increase. Increase in pulse-oximeter saturation is frequently the goal but LRM might be needed even when saturations are still normal.

Sometimes there is an advantage in using PCV over VCV in studies with obese patients. PCV is less safe because the tidal volume can fluctuate when total lung-compliance changes. Volume guaranteed PCV was therefore introduced. The only difference now between PCV and VCV is its flow pattern. This contrasts a decelerating flow in PCV versus constant flow in VCV. The indication for employing a decelerating flow might be found when oxygenation at 60% FiO₂ cannot be maintained in a patient even when sufficient lung recruitment and PEEP is given while cardiac output is not depressed. The
decelerating flow pattern of PCV fills the alveoli earlier and increases the diffusion time through the alveolar wall. Other theories suggest that the almost ‘explosive’ flows that occur at the start of the ventilation cycle improve the diffusion of oxygen into all alveoli.

Variable volume ventilation with PEEP as used in experimental settings on intensive care units will inflate different lung-areas in each cycle. This prevents atelectasis and increases the number of alveoli that take part in the gas exchange process without increasing the minute volume ventilation. This could be the reason why pressure support ventilation is more effective than PCV in improving oxygenation.\textsuperscript{16} Large tidal volume ventilation itself does not improve oxygenation.\textsuperscript{17} High inspiratory oxygen fraction although frequently used in morbid obese patients does not improve outcome.\textsuperscript{18} Another method that might receive more attention in the future is the use of Xenon. Xenon has a high molecular weight and increases gas density. Using it keeps the lung open at lower PEEP values and therefore creates less haemodynamic deterioration.

Key Learning Points

- Higher levels of PEEP are required for morbidly obese patients but a further increase in PEEP is not required during pneumoperitoneum.
- The beach chair position is very important for morbid obese patients. If possible apply this before induction of anaesthesia, during surgery and after awakening in the PACU.
- Each time PEEP is discontinued a lung recruitment manoeuvre is needed even if saturation is still normal as atelectasis develops early and is the principal problem in obese patients.
- The use of pressure support ventilation is more important than the standard use of volume versus pressure controlled ventilation.
- Permissive hypercapnia not only protects the lung from volutrauma but also improves peripheral perfusion.
References