Respiratory management of the obese patient undergoing surgery

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Abstract: As a reflection of the increasing global incidence of obesity, there has been a corresponding rise in the proportion of obese patients undergoing major surgery. This review reports the physiological effect of these changes in body composition on the respiratory system and discusses the clinical approach required to maximize safety and minimize the risk to the patient. The changes in respiratory system compliance and lung volumes, which can adversely affect pulmonary gas exchange, combined with upper airways obstruction and sleep-disordered breathing need to be considered carefully in the peri-operative period. Indeed, these challenges in the obese patient have led to a clear focus on the clinical management strategy and development of peri-operative pathways, including pre-operative risk assessment, patient positioning at induction and under anesthesia, modified approach to intraoperative ventilation and the peri-operative use of non-invasive ventilation (NIV) and continuous positive airways pressure.

Keywords: Obesity; respiratory perioperative management

Introduction

Obesity, as defined by a body mass index (BMI) of ≥30 kg/m² (1), has almost doubled since 1980 to affect an estimated 671 million individuals worldwide (2). Furthermore, morbid obesity, defined as a BMI above 40 kg/m², is rising (3). In the United States, China and United Kingdom (UK), obesity has a current prevalence of 32%, 4% and 25%, respectively in adult males and 34%, 5% and 25% respectively in adult females (2). The direct cost to the NHS in England for treating obesity, and its related morbidity, is estimated to be above £4 billion (4). The UK reported a 30-fold increase in the number of bariatric surgical procedures over ten years, a ten-fold increase in the number of hospital episodes primarily related to obesity over a decade (5) and it has been estimated that 25% of all UK patients admitted to intensive care units (ICU) are obese with 7% morbidly obese (6). It is therefore not surprising that the respiratory management of obese subjects, in particular in the pre- and peri-operative stage, represents a growing challenge to surgeons, pulmonologists, anesthetists and intensivists (7,8).

This review will detail the physiological effects of obesity on the respiratory system and report the evidence-based strategies to manage the pre- and peri-operative phase.

Obesity-related changes in respiratory physiology

Effects of obesity on the respiratory system

Obesity is associated with increased work of breathing as a consequence of increased airways resistance and reduced respiratory system compliance (9-12) Lung volume falls as a function of obesity (13) as a result of the increased abdominal volume and visceral fat (14,15). Respiratory system compliance in the obese can be reduced by up to 35% (12) due to (I) the restrictive effect of mass loading on the chest wall (15,16); (II) a tendency to breathe at low lung volumes (17,18); and (III) the effect of fat distribution that contributes to high pleural pressures and leads to low end-expiratory volumes with expiratory flow limitation when supine (19). The decrease in overall compliance, however, is principally driven by a decrease in lung compliance, in

turn, being the result of an increased pulmonary blood volume (20). Breathing at low volumes increases airway resistance (12) with expiratory flow limitation and gas trapping due to early airway closure and subsequent generation of intrinsic positive end-expiratory pressure (PEEPi) (20) and ventilation-perfusion mismatching, especially when supine and asleep (21). These phenomena serve to further increase work of breathing (14).

These physiological changes are heightened during sleep in the supine position due to the negative impact on the pulmonary mechanics of diaphragm impedance by the abdomen with a change in lung volume (15,22-24). This impairs the capacity of obese patients to tolerate apneic episodes with early onset oxygen desaturation (25). All these changes in pulmonary mechanics result in the obese patient having a lower functional residual capacity (FRC) and expiratory reserve volume (ERV) compared with normal weight subjects (26) with forced vital capacity (FVC), forced expired volume in one second (FEV_1) and forced mid-expiratory flow reduced in the morbidly obese (27).

Sleep disordered breathing

Sleep-disordered breathing, including obstructive sleep apnoea (OSA) and obesity-related respiratory failure (ORRF), is common in obese patients (28). Studies estimate the prevalence of OSA as 2-24% of the population (29,30) with half of all patients with a BMI above 40 kg/m^2 demonstrating OSA (31). Of major clinical importance, a recent meta-analysis reported that OSA is associated with a higher incidence of postoperative acute respiratory failure, cardiac events and ICU admission (32). ORRF encompasses three distinct clinical phenotypes.

Severe OSA

Chronic respiratory failure in these patients has been shown to be a consequence of a reduced hypercapnic ventilatory response at the end of an apnoeic episode (33). Patients with this clinical phenotype have insufficient post apnea hyperpnea to clear the carbon dioxide load that accumulates during the apnoea (34). Therefore, each apnea is associated with an increase in carbon dioxide load that is buffered by renal retention of bicarbonate, subsequently blunting the hypercapnic ventilator response.

Lone obesity hypoventilation syndrome (OHS)

OHS is defined as obesity (BMI ≥30 kg/m^2) with daytime hypercapnia ($PaCO_2$ >6 kPa or 45 mmHg) and sleep disordered breathing in the absence of other causes of hypoventilation (35). Recent update of the definition has extended this to include the presence of an elevated base excess or bicarbonate level which may facilitate early screening for these patients (36). The mechanism underlying OHS is not fully understood and although an imbalance between the neural respiratory drive, respiratory muscle load and respiratory muscle capacity results in alveolar hypoventilation and hypercapnia, the contribution of each has yet to be determined. In simple obesity, subjects breathe more rapidly at a lower tidal volume to reduce the respiratory muscle load and avoid hypoventilation. However, this response is absent in patients with OHS, resulting in hypoventilation. Both hypercapnic and hypoxic ventilatory challenges are blunted in OHS patients compared with simple obese patients, such that there is less ventilation for a given level of oxygen and carbon dioxide (37,38). The subsequent hypercapnia and hypoxia cause sleep fragmentation that further blunts the hypercapnic and hypoxic ventilatory response (39). The impairment of the hypercapnic ventilatory response, in particular, has been shown to correlate with the severity of nocturnal hypoventilation and improves following treatment with non-invasive ventilation (NIV) (40,41).

Combination of OSA and OHS

Up to 30% of patients with OSA have OHS (42). The mechanism of chronic respiratory failure in these patients is presumed to be a combination of a blunted hypercapnic ventilatory response at the end of an apneic episode and an imbalance between increased respiratory muscle load and reduced respiratory muscle capacity, resulting in alveolar hypoventilation.

Pre-operative assessment

Risk stratification

A number of recommendations are available to guide the clinician in the management of the obese patient undergoing surgery (43,44) along with a number of useful websites (see *Table 1*). The Association of Anaesthetists of Great Britain and Ireland guidance advises that a supine oxygen saturation of less than 96% requires consideration of a referral to a specialist respiratory physician. It has become common clinical practice to screen obese patients with a simple questionnaire that has high negative predictive value in excluding sleep disordered breathing (45). Screening

Table 1 Clinical websites for management of the obese patient undergoing surgery

https://www.asahq.org (Includes Practice Guidelines for the Perioperative Management of Patients with Obstructive Sleep Apnea)

http://www.sobauk.com/ [The Society for Obesity and Bariatric Anaesthesia (SOBA)]

http://www.aagbi.org/sites/default/files/Obesity07.pdf [Association of Anaesthetists of Great Britain and Ireland (AAGBI) Guidelines]

Table 2 Obesity surgery mortality risk (OSMR) (49) score. One point attributed to the presence of each risk factor

OSMR score	Predicted 90-day mortality
0-1	0.2%
2-3	1.1%
4-5	2.4%

Table 3 Obesity surgery mortality risk (OSMR) factors

Body mass index >50 kg/m^2

Male gender

Systemic hypertension

Age above 45 years

Presence of risk factors for pulmonary emboli

   Previous deep vein thrombosis or pulmonary embolus

   Pulmonary hypertension

   Obstructive sleep apnoea

   Obesity hypoventilation syndrome

   Poor mobility

for symptoms of OSA with instruments such as STOP-BANG and subsequent treatment of sleep disordered breathing has been shown to reduce the need for intensive care when managing obese patients (46). As part of the screening programme, further investigation such as clinic oxygen saturations, spirometry and overnight oximetry are considered useful. Indeed, in obese patients with oximetry proven sleep disordered breathing, defined as a 4% oxygen desaturation index above ten events per hour, the combination of reduced daytime clinic oxygen saturations (SpO_2) and FVC indicates high risk of obesity related respiratory failure (47). Specifically, an FVC of less than 3.5 L in men and 2.3 L in women or a clinic SpO_2 less than 95% in men and 93% in women predicts a $PaCO_2$ of above

6.0 kPa. As part of this pre-operative assessment, review of any problems encountered during previous anesthesia is undertaken with a focus on important co-morbidities, such as ischemic heart disease and chronic heart failure and a comprehensive assessment of the upper airway to estimate the risk of a difficult intubation. Surgical risk assessment tools are available for example to help predict those at highest risk of post-operative respiratory complications (48) and a mortality risk score specifically designed for the obese patient undergoing surgery is shown in *Tables 2,3* (49).

General physical condition

Cardio-pulmonary exercise testing (CPET) can identify high-risk patients and the data gained from CPET is associated with surgical outcome in non-cardiopulmonary surgery (50). McCulloch and colleagues (51) observed that in patients undergoing bariatric surgery, post-operative complications were significantly higher in the cohort with a peak oxygen consumption ($\dot{V}O_2$) levels less than 15.8 mL·kg^{-1}·min^{-1}. In a similar study group, Hennis and colleagues found that a low anaerobic threshold (AT) was associated with postoperative morbidity and increased length of stay (52). With this in mind, and with a focus on optimizing the physical condition of the patient, the clinician may consider pre-operative training to reduce the incidence of post-operative pulmonary complications albeit the evidence for this is limited (53).

Airway assessment

Reduced neck extension and flexion combined with limited mouth opening account for the majority of the difficult airway cases encountered in obese subjects (54). Other risk factors such as morbid obesity, large neck circumference (above 43 cm) and a Mallampati score of ≥3 should alert the clinician to a difficult intubation (55,56). In addition, the reduced FRC and ERV (28) of the obese in the upright posture are further decreased by placing the patient in the supine position with the potential for rapid oxygen desaturation (57). Adequate pre-oxygenation is therefore essential (58) and if performed whilst sitting, this extends the time before oxygen desaturation (59). By optimizing the position of the patient, with head and trunk elevation, severe oxygen desaturations can be avoided. It has been reported that 75% of morbidly obese patients are grade 1 Cormack-Lehane view on direct laryngoscopy (57) with the ramped position improving oxygenation and visualization of the glottis with support provided under the head and trunk (60).

Table 4 Intra-operative ventilatory strategy
PEEP above 5 cm H_2O with recruitment maneuvers applied VT 6-8 mL/kg IBW
Increase RR to control end-tidal carbon dioxide/arterial partial pressure of carbon dioxide and maintain pH >7.35 Optimal patient positioning
PEEP, positive end-expiratory pressure; VT, tidal volume; IBW, ideal body weight; RR, respiratory rate.

Intra-operative strategies

In morbidly obese patients, FRC decreases after induction of anesthesia by up to 50% due to atelectasis and blood shifting from abdomen to thorax (20,61,62). Increased intra-abdominal pressure transmitted in a cephalid direction towards the most dependent lung regions is coupled with decreased movement of the dependent part of the diaphragm to increase the likelihood of atelectasis (15). Indeed, atelectasis frequently persists through the postoperative period (63,64) and this contributes to the decrease in lung compliance of the respiratory system, which is more important than the fall in chest wall compliance (20).

A number of techniques have been suggested to optimize ventilation intra-operatively and reduce postoperative complications and these are summarized in *Table 4*.

Application of extrinsic positive end expiratory pressure (PEEP)

Katz and coworkers showed that the increase in lung volume caused by application PEEP is greater than that predicted from the pressure-volume relationship at lower PEEP (65). Indeed, PEEP defends against the fall in FRC associated with administration of general anesthesia and thereby prevents or, at least, reduces lung atelectasis (66-68) with evidence that the addition of PEEP improves intra-operative respiratory function (69-71). Pelosi *et al.* showed that applying 10 cm H_2O of PEEP resulted in improved oxygenation in morbidly obese patients, but not in normal weight subjects (72) and Azab and colleagues demonstrated PEEP reduced lung atelectasis with a reduction in post-operative pulmonary complications (73).

Extrinsic PEEP combined with recruitment maneuvers (RM)

Small airway opening can be achieved by applying intermittent hyperinflation of the lung, so called recruitment maneuvers (RM) (62). Although the clinician should avoid the associated negative haemodynamic effects, a number of recent studies suggest that the addition of PEEP in combination with RM improves oxygenation and lung compliance by reducing lung atelectasis (64,74-80). Talab and colleagues found that this intraoperative combination reduced post-operative pulmonary complications (81). Two recent large multi-centre RCTs found conflicting results for protective ventilation. The IMPROVE study (82) included 400 patients at risk of postoperative pulmonary complications undergoing major abdominal surgery demonstrated that lung protective ventilation using low tidal volumes ventilation with a PEEP of 6 to 8 cm H_2O combined with RM reduced post-operative complications and shortened hospital length of stay. A recent large French multi-centre observational study of 2,960 patients found that BMI was an independent factor for the use of tidal volume of above 10 mL/kg ideal body weight (IBW) (83). Interestingly, only 25% of patients with a BMI greater than 30 kg/m^2 and 35% with a BMI greater than 35 kg/m^2 received additional PEEP and only 18% of the obese patients receiving RMs. A tidal volume of 6-10 mL/kg IBW and a respiratory rate to maintain normocapnia has been recommended (84,85). Finally, a recent meta-analysis (86) of three randomized studies of ventilation in obese patients, comparing pressure with volume ventilation found no difference between ventilation modes in terms of intraoperative oxygenation, tidal volume, mean airway pressure, mean arterial pressure and heart rate.

Positioning of the patient

A number of different patient positions have been reported. Valenza and colleagues showed that PEEP in combination with the 'beach chair position' improved oxygenation and pulmonary elastance (87) whilst the reverse Trendelenburg position mitigates against increased intra-abdominal pressure improving oxygenation and lung compliance (88,89). Lateral decubitus position, by shifting the abdominal pannus away from the diaphragm, can also decrease the intra-abdominal pressure and increase chest excursions (57).

Post-operative stage

Pulmonary complications

Obese patients are more likely to develop post-operative acute respiratory failure (90) and have higher rates of pneumonia, prolonged mechanical ventilation and weaning difficulty (58,91-95). Guidelines recommend extubating patients with existing ORRF in an awake state and to

avoid the supine position (46). Indeed, the post-operative pulmonary complications are associated with increased rates of short-term and long-term mortality (96). Both upper abdominal and thoracic surgery can result in a restriction of pulmonary function that can persist for several days as a direct cause due to the reduced ability of the patient to clear secretions (64). Furthermore, the immediate post-operative period can pose an increased risk for respiratory complications in obese patients with OSA and OHS as opiate sensitivity contributes to the severity of nocturnal hypoxia (97,98). In addition, obesity increases the post-operative work of breathing (15,20) as lung atelectasis causes the patient to breath at lower lung volumes with associated early airways closure and expiratory flow limitation resulting in development of intrinsic PEEP (22,99). This is worsened further when supine (14).

Non-invasive ventilator support (CPAP and NIV)

Continuous positive airway pressure (CPAP) and NIV have been used to prevent and treat acute respiratory failure after surgery or to treat acute respiratory failure (100,101). In an ICU telephone survey in France, 69% of physicians reported to use CPAP and NIV as first line treatment in patients with post-operative acute respiratory failure (102). This is supported by a systematic review of the use of post-operative NIV and CPAP (103), of which 19 of 29 studies observed improved gas exchange, 11 reported a reduced re-intubation rate and one study showed NIV improved clinical outcome (104). CPAP provides ventilatory support to restore and maintain the lung volumes by recruiting atelectatic lung which, in turn, improves oxygenation and reduces work of breathing. Animal studies have shown that minimizing lung atelectasis decreases bacterial growth and translocation of organisms to the bloodstream by reducing the permeability of the epithelial-endothelial barrier (105,106). A meta-analysis (107) has shown that post-operative CPAP following abdominal surgery significantly reduced post pulmonary complications, atelectasis and pneumonia which is in contrast with a more recent Cochrane review concluding that the evidence to support the use of CPAP to reduces pneumonia and re-intubation is of low quality (108). However in this Cochrane review, only one study included obese patients and the review excluded use of intra-operative PEEP (109). This can be balanced against the results of a randomized controlled trial that showed applying CPAP to morbidly obese patients immediately following extubation led to improved spirometry at 24 hours compared to delaying the initiation of external CPAP to the recovery room (110).

The feasibility and safety of NIV use in the recovery room after various types of surgery has been demonstrated (106,108,111,112). One study showed a 16% absolute risk reduction in post-extubation acute respiratory failure with a reduced length of ICU stay by application of 48 hours of NIV in the immediate post-operative stage for patients with a BMI above 35 kg/m^2 (113). A limitation of the study was the use of a historically matched control group (114). Although there are no clinical trials that have shown the effectiveness of NIV in the post-operative setting for the management of patients with established chronic respiratory failure it is considered the standard of care (113,115-117).

Post-operative ventilation strategy

If a patient requires extended ventilation, the clinician should give careful consideration in their decision for the most appropriate tidal volume and this should be based on ideal and not actual body weight to avoid high peak and plateau airway pressures and barotrauma. As a consequence of the effect of general anesthesia and surgery, the obese patient demonstrates lung atelectasis with a fall in lung volumes and increased airway resistance. Because of the reduced chest wall compliance of respiratory system in obesity, inflation pressures should be interpreted with caution with the initial target tidal volume calculated from the IBW and then adjusted according gas exchange (118). Pelosi and colleagues demonstrated that the addition of PEEP at 10 cm H_2O in morbidly obese patients increased elastance and improved oxygenation compared with non-obese subjects (62). Of clinical relevance is that the use of a low tidal volume and a high fraction of inspired oxygen in the obese population can lead to progressive formation of atelectasis, with secondary hypoxemia and hypercapnia (119). The goal for mechanical ventilation in this patient population should focus on the use of peak inspiratory pressures high enough to open collapsed lung regions and the use of PEEP to keep the alveoli open at the end of expiration (120). 'Safe' peak plateau pressures in the obese patient differ from the non-obese patient as these obese patients, due to a reduced chest wall compliance, have increased pleural pressures resulting in a lower transpulmonary pressure and less lung distension. Thus, indirect measurements of transpulmonary pressures using oesophageal pressure monitoring can be useful to assist the clinician in the delivery of the ventilator strategy in the physiologically complex patients based on

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Table 5 Respiratory management of the obese surgical patient—a summary

Pre-operative assessment

    Screening for symptoms of sleep-disordered breathing with specialist respiratory referral if suspected (STOP-Bang questionnaire)

    Assessment for co-existent respiratory and cardiac disease

    Upper airway assessment e.g., Mallampati score

    Mobility assessment

    Baseline oxygen saturations on room air and spirometry

Pre-operative planning

    Peri-operative continuous positive airways pressure and non-invasive ventilation

    Operative ventilation strategy

    Peri-operative patient positioning

    Intra- and post-operative analgesia e.g., opiate load and regional anesthesia

    Postoperative care location

Intra-operative management

    Application of positive end-expiratory pressure

    Application of recruitment maneuvers

    Patient positioning

Post-operative management

    Non-invasive ventilation or continuous positive airways pressure

    Respiratory physiotherapy

    Careful fluid balance management

    Patient positioning

    Early mobilization

transpulmonary pressure measurement (121).

Respiratory physiotherapy and early mobilization

Incentive spirometry, respiratory physiotherapy, and targeted pulmonary toileting should be instituted in the immediate post-operative stage (122). Early mobilization, albeit a complex task involving a large team with an associated risk, is suggested (87). This approach is supported by a study in obese patients following major abdominal surgery, which showed that respiratory and rehabilitation physiotherapy, including coughing, deep breathing and early mobilization, reduced post-operative complications (123).

Conclusions

The respiratory management of the obese surgical patient provides a number of peri-operative challenges. There is a growing evidence base in a number of key areas, in particular, around optimal ventilation strategies to minimize the risk of immediate post-operative pulmonary complications (*Table 5*). The elective clinical pathway for such complex patients must be carefully considered taking into account pre-operative assessment and planning as well as peri- and post-operative management.

Acknowledgements

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