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Intensive care in the obese

Klaus Lewandowski, MD, Professor of Anaesthesia and Intensive Care [a,*], Monika Lewandowski, MD, Physician [b,c]

[a] Department of Anaesthesia, Critical Care and Pain Therapy, Elisabeth-Krankenhaus Essen, Klara-Kopp-Weg 1, 45138 Essen, Germany
[b] Essen, Germany

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Nearly 20% of all patients admitted to an intensive-care unit are obese. Their excess weight puts them at risk for several problems and complications during their intensive-care unit stay. Especially, pulmonary problems need particular attention, and comprehensive knowledge of the specific pathophysiologic changes of the respiratory system is important. Lung protective ventilation strategies, supplemented by lung-recruiting manoeuvres, may be feasible in critically ill obese patients with lung injury. Careful positioning of the obese is essential to optimise ventilation and facilitate weaning from mechanical ventilation. Optimal hypocaloric nutrition with a high proportion of proteins is advised to control hyperglycaemia. Because mortality in obese patients is similar to or lower than in non-obese ones, it is conceivable that obesity has a protective effect in the critically ill.

History

> Repletion, carried to extremes, is perilous.
> (Hippokrates, Aphorisms I.4)[1]

Today's paintings, illustrations, cartoons, advertisements and photographs display obese people as plump, fleshy, flabby and bloated individuals, who are subject to discrimination. In history, the perception of the obese was quite different. Obesity was a measure of prosperity and high social status, and obese persons were depicted respectfully and with dignity. Very ancient historical traces tell us that obesity has always been affiliated with mankind.

* Corresponding author. Tel.: +49 201 897 3701; Fax: +49 201 897 3709.
E-mail address: k.lewandowski@contilia.de (K. Lewandowski).
[c] Currently no affiliation, contact via corresponding author.

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The earliest sculpture of an obese woman was found in the Hohle Fels Cave in the Swabian Jura of southwestern Germany in the year 2008. The figurine was carved at least 35 000 calendar years ago.[2] A further prehistoric masterpiece of art is the famous Venus of Willendorf, sculpted 30 000–22 000 BC, showing an obese woman with opulent breasts and hips. It is, however, not quite clear whether the artists over-accentuated the corpulence inventively or whether they depicted a real person.

Super-obese individuals were also portrayed in ancient literature. Athenaeus, a Greek rhetor,[3] wrote *The Deipnosophists* in the early part of the 3rd century AD. He described Ptolemaeus, a Macedonian ruler, with the words "… his whole body was eaten up with fat, and with the greatness of his belly, which was so large that no one could put his arms all round it." Further, his son Alexander became exceedingly fat "… he was not able even to walk, unless he went leaning on two friends …" King Magas, a further member of the Ptolemaeian dynasty, also "… became, towards the end of his life, so immensely bulky and burdensome to himself, that he was at last actually choked by his fat …"

Epidemiology

Overweight has become a global epidemic weighing heavily on the health system. With continuous rise of the obese population, obesity and obesity related disorders are a frequent challenge in nowadays' intensive care.

Worldwide, there are more than 1 billion overweight adults of whom at least 300 million are obese.[4] The International Association for the Study of Obesity (IASO) reported measured body mass index-data for several European countries.[5] Top positions with respect to the incidence of overweight are held by the Czech Republic, Ireland, Scotland and Germany with more than 66% of all men being fat. Scotland and England are leading in female overweight: more than 55% present with a body mass index (BMI) $\geq 25\ \mathrm{kg\,m^{-2}}$. Obesity causes morbidity and disability, and increases the risk for a wide range of chronic diseases. Life expectancy is shortened by 8–10 years in morbidly obese persons so that this generation is the first predicted to have a shorter lifespan than their parents.[6]

With the rising obese population, we increasingly encounter obesity in intensive-care units (ICU). Ray et al. recorded the height and weight of 2148 patients admitted to a medical ICU and reported 27% of them being overweight (BMI 25–29.9 $\mathrm{kg\,m^{-2}}$). Eighteen percent were obese with a BMI of 30–39.9 $\mathrm{kg\,m^{-2}}$ and 7% were severely obese with a BMI of $\geq 40.0\ \mathrm{kg\,m^{-2}}$.[7] Sakr et al.[8] analysed admissions to 198 ICUs in 24 European countries with BMI data available in 2878 patients. Overweight was observed in 36% of the patients, 15% were obese and 3% severely obese.

Pathophysiology of the respiratory and cardiovascular system

Obesity changes the physiology of a variety of organ systems. Of these, the respiratory and cardiovascular functions are markedly impaired, which, in turn, influence the expected physiologic response especially to critical illness. The most important pulmonary changes in obesity are subsumed in Table 1.

The specific pathophysiological changes of the cardiovascular system have their origin in the cardiovascular disease that dominates – besides diabetes – morbidity in obesity.[9] Obese persons (BMI $\geq 30\ \mathrm{kg\,m^{-2}}$) have a prevalence of arterial hypertension ranging from 38% (women) to 42% (men). Mean systolic and diastolic blood pressures rise with increased BMI in men and women.[10]

Pericardial fat is visceral adipose tissue and is a risk factor for atrial fibrillation.[11] Obese individuals have a 49% elevated risk of atrial fibrillation compared with persons of normal weight. Risk increases with greater BMI.[12]

Moderate overweight and obesity are also associated with a higher risk of coronary heart disease.[13] In obesity, left-ventricular dilation, left-ventricular hypertrophy and left-ventricular dysfunction can be observed. Right ventricular structure and function may be similarly altered. Finally, obesity cardiomyopathy is common in persons with severe and long-lasting obesity.[14]

Frequent problems of obese patients in the ICU

Managing obese and morbidly obese patients in the ICU is challenging and implicates a host of problems. The ICU has to be equipped with special beds, lifts, long instruments, etc. Routine procedures

Table 1
Most important pathophysiological pulmonary changes in obesity.

Parameter	Cause/effect
Decreased compliance of the respiratory system	Caused by accumulation of fat tissue around the chest wall, ribs, diaphragm and abdomen; possibly also caused by pulmonary vascular engorgement[15] Impaired lung expansion caused by abdominal and intraabdominal fat masses Compliance of lung, chest wall and total respiratory system declines with increasing BMI[16] Result: shallow rapid breathing and increased work of breathing[17]
Reduced lung volumes	Functional residual capacity (FRC) declines exponentially with increasing BMI[16] leading to small airway closure, ventilation-perfusion mismatch, right-to-left shunting, and arterial hypoxaemia Mainly due to the reduction in FRC, the obese patient's capacity to tolerate periods of apnoea is significantly impaired
Oxygen consumption	Oxygen consumption and carbon dioxide production are increased due to metabolic activity of the excess fat; oxygen consumption rises disproportionally with exercise[17]
Gas exchange	Only modestly impaired when at rest, awake and spontaneously breathing in an upright position; severe impairments in the postoperative period[15] or when lying in supine position
Obstructive sleep apnoea (OSA), obstructive sleep hypopnoea (OSH)[18]	OSA: complete airway obstruction during sleep for more than 10 s apnoea time; OSH: airflow reduction of more than 50% despite continuous breathing attempts; OSA and OHS lead to hypoxaemia and hypercapnia Presumably 90% of obese patients suffer from OSA[19] Increased susceptibility to the respiratory depressant effects of sedatives, opioids and anaesthetics Patients with OSA are at increased risk of difficult intubation Frequent postoperative complications: hypoxia, apnoea, respiratory arrest, hypertension, cardiac arrhythmias, cardiac arrest

such as insertion of central venous catheters or arterial lines will be risky in the severely obese. However, only few high-quality studies that give us valid information about our clinical decision making have been published. In most cases, the intensivist must rely on his experience, judgement and improvisational talent. Frequent problems are compiled in Table 2; however, most of the studies that report these problems are of retrospective nature, have been extracted from databases or represent recommendations from review articles. In conclusion, the results need to be interpreted with caution.

Frat et al.[20] presented a well-performed, large, prospective, matched-pairs study that compared mechanically ventilated obese patients (BMI ≥ 35 kg m^{-2}) with non-obese patients (BMI < 30 kg m^{-2}). During the ICU stay, they observed no significant differences regarding incidence of renal failure, pressure ulcers, ventilator-associated pneumonia, catheter-related infection or endotracheal re-intubation. Only difficulties during tracheal intubation and post-extubation stridor were more frequent in obese patients. Dossett et al.[21] prospectively studied a large series of obese patients admitted to the ICU. They documented obesity to be an independent risk factor for catheter-related and other bloodstream infections. Contradictory to other investigators, pneumonia rates were not associated with BMI.

Anaya and Dellinger[22] have summarised multiple studies on infection and obesity, and reported a higher risk for surgical site infection (SSI) in patients with obesity. The following reasons for the higher rates of SSI in this patient collective are discussed: (1) obese patients have co-morbidities such as diabetes mellitus, which is an independent predictor of SSI; (2) obesity is associated with longer

Table 2
Possible problems of obese patients in the ICU.

Problem	Clinical aspects to consider in the obese
Higher risk of surgical site infections[22,27,28]	Intensified insulin therapy, supplemental oxygen postoperatively,[23] adequate tissue concentration of antibiotics[24]
Higher rate of ICU acquired infections[8]	
Hyperglycaemia[29]	Tight glycaemic control, intensified insulin therapy
Hyperglycaemia enhances the risk for critical illness neuromuscular abnormalities[30]	Tight glycaemic control[30]
Postoperative cardiac complications, myocardial infarction[27]	Early identification of cardiac problems by close monitoring,[31] providing appropriately sized cuffs for blood pressure monitoring, liberal use of invasive arterial pressure monitoring
Atrial fibrillation in patients with waist circumference >102 cm and elevated C-reactive protein after coronary artery bypass grafting[32]	Continuous ECG-control
Obstructive sleep apnoea[33]	Therapy with continuous positive airway pressure[33]
Respiratory failure[8,34]	Continuous pulse oximetry, blood gases monitored at close intervals, post-extubation respiratory failure can be successfully treated with non-invasive ventilation; prophylactic use of non-invasive ventilation in severely obese patients post-extubation may be reasonable[35]; reluctant use of sedation[31]; positioning therapy, recruitment of atelectatic lung tissue; no fluid overload
Increased risk for pneumonia[34]	Physiotherapy[36]
Increased risk for ARDS[26,34]	Early identification and elimination of risk factors for ARDS
Intubation/extubation related difficulties and complications[20,27]	Use of ramped position for intubation,[37] extubation in semi-recumbent position,[38] quick access to adequate equipment (laryngoscopes, bronchoscope, large anaesthesia masks, …)
Higher frequency of mechanical ventilation[8,39]	Leads to shortage of ICU beds or respirators → ethical problems[40]
Prolonged time on mechanical ventilation[39]	Leads to shortage of ICU beds or respirators → ethical problems[40]
Increased risk of multiple organ failure[34,41]	
Increased risk of renal failure[28,34]	
Increased risk of catheter-related infections[21]	Early change of catheters in case of signs or symptoms of infection[21]
Increased risk for urinary tract infections[27,34]	Frequent inspection of urinary catheters
Impaired wound healing/skin necrosis[42]	Wound management with pain control, appropriate size of dressings, adequate tissue levels of antibiotics; treatment of hypoperfusion, hypoxia, and hyperglycaemia[43]
Decubital ulcers[34]	Regular turning of the patient, use of pressure reduction mattresses, prevent malnutrition, administration of sufficient proteins, encourage early mobilization[43]
Deep vein thrombosis[34] and pulmonary embolism[28]	Combined mechanical and pharmacologic prophylaxis, higher doses of prophylactic anticoagulating agents are required, dosage should be carefully considered for each obese patient individually[31]
High risk of neural injuries[27,38]	Need for special equipment (beds, lifting devices), padding of pressure points[38]
Prolonged ICU stay[8,39]	Leads to shortage of ICU beds or respirators → ethical problems[40]

duration of operation, which is one predictor of SSI – performing laparoscopic operations whenever feasible can reduce SSI; (3) obese persons exhibit hypoperfusion and decreased oxygen tension in their adipose tissues – supplemental oxygen intra-operatively and postoperatively can decrease the rate of SSI[23]; and (4) tissue concentrations of prophylactic antibiotics are too low – a higher dose of prophylactic antibiotic can decrease the rate of SSI.[24]

There is still a discussion on whether obese patients are at higher risk for development of acute lung injury (ALI) or acute respiratory distress syndrome (ARDS)[25] or sepsis. In a very recent study, Gong et al.[26] analysed 1795 patients admitted to an ICU, and who had risk factors for ARDS. The authors documented increasing BMI associated with increased risk for development of ARDS.

Emerging scientific understanding supports the hypothesis that visceral obesity plays a key role in the pathogenesis of resulting problems and complications in the postoperative ICU setting. Abdominal fat masses are associated with a chronic inflammatory state of the whole body, hypercoagulability, hyperglycaemia and metabolic syndrome, which put the obese patient at risk of increased postoperative morbidity and mortality.

Airway management

Some clinical reports claimed difficulties with mask ventilation, laryngoscopy and tracheal intubation in the obese. A recent study analysed data from 91 332 patients and reported a BMI of 35 kg m^{-2} or more to be a risk for difficult tracheal intubation with an odds ratio of 1.34.[44] Further, an important predictor of difficult intubation is a neck circumference greater than 43 cm.[45] Airway management of the obese can become a real challenge in an emergency situation where there is no time for adequate preparation. ICUs should be appropriately equipped to manage difficult intubation of obese patients, and the personnel should receive special training in airway management.[46] Intubation difficulties can be minimised by proper positioning of the patient. Laryngeal view is significantly improved, if patients are positioned in the “ramped position.”[37] If an obese patient cannot be intubated or ventilated via a face mask, a laryngeal mask is recommended as a primary salvage therapy.[46]

In obese patients scheduled for endotracheal intubation, optimal preoxygenation is vital because they desaturate more rapidly during apnoea than non-obese patients. Ideally, the upper part of the body should be elevated to a semirecumbent position. Application of a positive end-expiratory pressure (PEEP) of 10 cmH_2O during preoxygenation with FiO_2 1.0 can increase the duration of non-hypoxic apnoea by 50% in morbidly obese patients.[47] After safe intubation, FiO_2 should be reduced. Obese patients (BMI 25–35 kg m^{-2}) treated with intra-operative low-inspiratory oxygen concentrations fared better than those treated with high-inspired oxygen concentrations; they had reduced small-airway collapse, better lung function and arterial oxygen saturation during the first 24 h postoperatively.[48]

There remains controversy on whether or not routine rapid sequence induction (RSI) should be performed in patients with obesity. Freid[49] comprehensively reviewed this topic and concluded that RSI makes sense in obese patients with symptomatic gastro-oesophageal reflux and other conditions associated with the risk of pulmonary aspiration. In the elective, fasted, obese patient with no risk factor for pulmonary aspiration, it might be reasonable to perform induction without RSI.

Post-extubation stridor is frequent in obese patients.[20] It is recommended to plan extubation carefully and to extubate the patient’s trachea, only if he is fully awake and has received an increased inspired oxygen concentration several minutes prior to extubation. If re-intubation is imminent, extubation should be performed in the ‘ramped’ position; otherwise, a semirecumbent or a reverse Trendelenburg’s position is useful.[46]

Ventilatory strategies

Respiratory failure type III (‘perioperative respiratory failure’) according to the renowned classification by Hall et al.[50] probably is the primary reason that obese patients require postoperative respiratory support.[51] The main characteristic of perioperative respiratory failure is marked atelectasis of lung tissue.

Ventilatory management of respiratory failure of non-obese patients should be lung protective and aim at early weaning. It is important to bear in mind that the therapeutic options (including mechanical ventilation, MV) that have been suggested for treatment of the various forms of respiratory failure have not yet been formally evaluated in overweight or obese cohorts. Currently, no guidelines exist on which ventilatory strategy to use in this patient collective. Furthermore, most of the ventilatory strategies reviewed and discussed here are derived from studies in pulmonary healthy obese patients who underwent bariatric surgery. These strategies may be effective postoperatively but not in obese patients with ALI. Whatever ventilation strategy is applied, it must be remembered that the lung does not grow with increasing BMI. The tidal volume for the overweight and obese patient has to be adjusted to the ideal body weight, not the measured body weight, to prevent the lung from harmful overdistension.

Lung protective MV

A decade ago, the ARDS Network reported on the effect of a lung-protective, low-tidal-volume ventilation strategy that led to a 22% reduction in mortality in ALI/ARDS patients.[52] Not universally known is that 58.6% of the patient population were overweight or exhibited even higher grades of obesity. This was because inclusion criteria allowed investigators to study patients whose measured body weights were as high as 1 kg cm^{-1} of their body heights. This roughly corresponded to a BMI of 60 kg m^{-2}. A retrospective reassessment of the data revealed that important primary and secondary outcome data, such as 28-day mortality rate, 180-day mortality rate, ventilator-free days and not achieving unassisted ventilation by day 28 were not statistically different between normal weight, overweight or obese patients.[53]

These facts suggest that overweight or obese patients with respiratory failure may be ventilated according to the protocol of the ARDS Network Study: V_T: 6 ml kg^{-1} ideal body weight; plateau pressure $\leq$ 30 cmH_2O; ventilation mode: assist control; respiratory rate: 6–35 min^{-1} (aim: pH: 7.3–7.45); the ratio of the duration of inspiration to the duration of expiration (I:E ratio): 1:1–1:3; oxygenation goal: partial pressure of O_2 in the blood (PaO_2) 55–80 mmHg or the amount of oxygen attached to the red blood cell in the blood (SpO_2) 88–95%, PEEP: 5–24 cmH_2O as specified in the so-called ‘PEEP table’.[52]

A principal question remains: Is it appropriate to recommend using this strategy in overweight and obese patients? In the absence of ventilator protocols specifically designed for obese patients, it might be beneficial to implement lung protective MV as described in the ARDS Network Study.

In obese patients, it may be difficult to stay within the recommended plateau pressure limits. Addressing this issue, early experimental data from Dreyfuss et al.[54] are helpful. These authors applied inflation pressures of 45 cmH_2O in mechanically ventilated rats. Ventilator-induced lung injury was less pronounced in rats strapped with rubber bands around the thorax and abdomen (acting as a cuirass) compared with unstrapped animals. The authors concluded that the cuirass limited pulmonary overdistension. A comparable situation is present in obese patients in whom overdistension of the lungs is limited by the large thoracic fat masses and the elevated intra-abdominal pressure that also act as a cuirass (Fig. 1). Therefore, application of high plateau pressures may be less harmful in obese than in non-obese patients.

Mode of MV

There are few studies evaluating the application of volume-controlled mechanical ventilation (vcCMV) versus pressure-controlled MV (pcCMV) in obese patients. Furthermore, these studies were performed in obese patients without severe pulmonary restriction and during laparoscopic surgery. De Baerdemaeker et al.[55] studied 24 patients with a BMI > 35 kg m^{-2} scheduled for gastric banding. Fifteen minutes after establishment of capnoperitoneum, patients were randomly divided into the vcCMV and pcCMV groups. The authors reported similar results for either ventilation mode. Carbon-dioxide elimination was more effective in the vcCMV group. Cadi et al.[56] studied 36 patients with BMI > 35 kg m^{-2} during laparoscopic bariatric surgery and documented a better intra-operative oxygenation in the pcCMV group. They explained this finding with an improvement of the ventilation/perfusion ratios and a better alveolar recruitment during pcCMV. Hans et al.[57] did not detect a difference in oxygenation parameters when they compared pcCMV with vcCMV in 40 morbidly obese patients undergoing gastric bypass surgery. The authors observed, however, marked increases of PaO_2

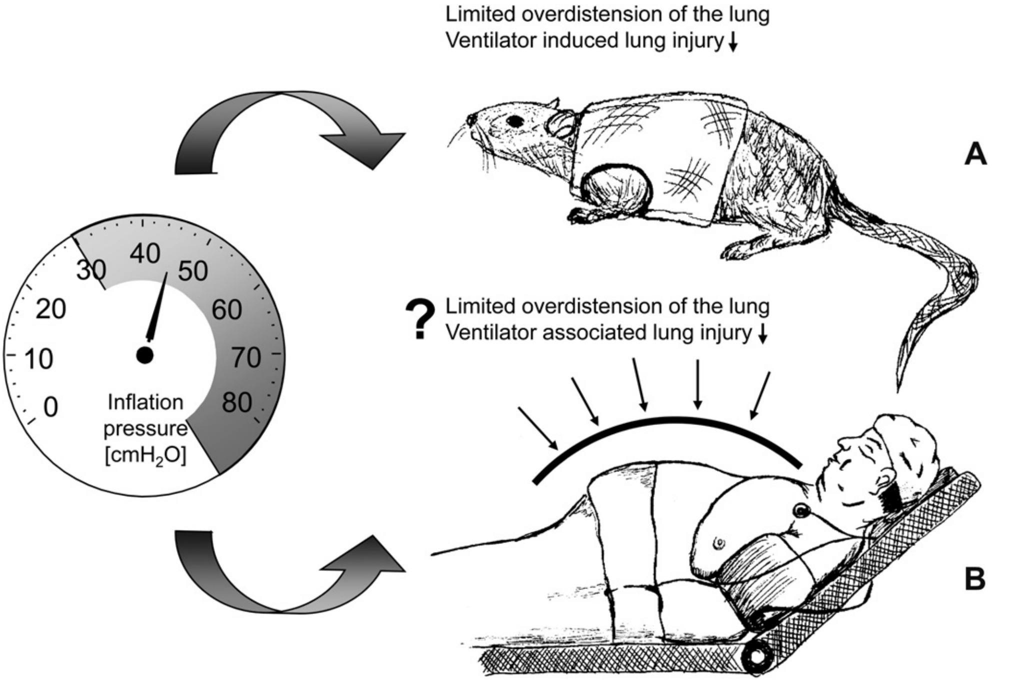

Fig. 1. A thoraco-abdominal cuirass protects from lung overdistension induced by high inflation pressures; (A) experimental setting, (B) obese human: fat masses surrounding the thorax and abdomen and a high intra-abdominal pressure act as a cuirass (sketches drawn by Mrs. Mareike Karl, Elisabeth-Krankenhaus Essen, Germany).

in 10 patients with pcCMV. For treatment of critically ill obese patients who develop hypoxaemia, it might be reasonable to recommend testing of both ventilation modes.

A recent study compared intra-operative pressure-support ventilation with pcCMV in 68 moderately obese patients. Pressure-support ventilation was superior to pcCMV as intra-operative and postoperative oxygenation was significantly better.[58] Probably, a trial of this ventilation mode in mechanically ventilated obese patients is warranted.

PEEP and lung-recruiting ventilatory strategies

Obese patients have a great potential for atelectasis. PEEP and lung-recruiting ventilatory strategies can open atelectatic lung regions and prevent them from re-collapse. Pelosi et al.[59] measured lung volumes and mechanics in nine obese patients (BMI > 40 kg m^{-2}) and nine non-obese controls postoperatively after abdominal surgery. A PEEP of 10 cmH_2O significantly improved respiratory mechanics and oxygenation in the obese but not in patients with normal weight. In severely obese patients, PEEP levels up to 15 cmH_2O may be indicated to prevent loss of ventilated lung volume and maintain a normal functional residual capacity (FRC).[60] PEEP alone, however, may not always protect the lung from derecruitment. Reinius et al.[61] investigated 30 patients (BMI 45 ± 4 kg m^{-2}) undergoing gastric bypass surgery and documented that an intra-operative PEEP level of 10 cmH_2O alone did not reduce atelectasis or improve oxygenation. A recruitment manoeuvre with 55 cmH_2O for 10 s without PEEP also had no sustained effect on these parameters. Only the recruitment manoeuvre followed by PEEP was effective. These results were confirmed by another working group that documented a vital capacity manoeuvre followed by PEEP 10 cmH_2O to effectively prevent lung atelectasis and deterioration of oxygenation during and after bariatric surgery.[62] Best lung-recruiting results in obese patients, however, might be achieved when the vital capacity manoeuvre (inspiratory pressure of

40 cmH_2O for 15 s) is repeated every 10 min, and is combined with a basic PEEP level of 10 cmH_2O.[63] All strategies have been studied in pulmonarily healthy obese patients. It is not known whether they are effective and safe in the injured lung. Furthermore, it has to be kept in mind that recruitment manoeuvres may cause severe cardiocirculatory complications.

Weaning and non-invasive ventilation

Weaning from MV may be difficult in the obese. Obstructive sleep apnoea and hypoventilation syndrome combined with hypercapnia are common in these patients, and may prolong or obviate weaning. Weaning might, furthermore, be compromised by the presence of basal atelectases and high intra-abdominal pressure. Up to now, no studies on weaning of obese patients have been undertaken.

Nevertheless, for these patients, it may be reasonable to facilitate weaning by bringing the patient in the reverse Trendelenburg's position and establish non-invasive ventilation (NIV) immediately after extubation. Burns et al.[64] have reported the 45° reverse Trendelenburg's position to result in the optimal spontaneous breathing pattern with large tidal volume and low respiratory rate in patients with a large abdomen.[64]

NIV may be a preventive therapy to reduce postoperative respiratory failure after extubation and may be able to reestablish preoperative lung function. El Solh et al.[35] investigated 62 severely obese patients, who received NIV immediately post-extubation for 48 h. The authors recorded a lower rate of post-extubation respiratory failure (10% vs. 26%, $p = 0.03$), a shorter duration of ICU stay (11.8 days vs. 18.2 days, $p < 0.001$) and hospital stay (20.6 days vs. 26.0 days, $p = 0.007$) in the NIV group when compared with conventionally treated patients. The authors advocate prophylactic use of NIV immediately after extubation in patients with morbid obesity. One drawback of the study, however, is the use of a historical control group. In a recent study, Neligan et al.[65] prospectively investigated 40 severely obese patients with OSA postoperatively after laparoscopic bariatric surgery. The patients were randomly assigned to NIV immediately post-extubation or to supplemental oxygen without NIV. Immediate start of NIV after extubation significantly improved spirometric lung function 1 and 24 h postoperatively. Direct implementation of NIV after extubation may protect the severely obese patient from respiratory failure and re-intubation.

Positioning

With inappropriate positioning, the obese patient can experience serious physiologic impairment and physical injury. Understanding the physiologic alterations that occur when the body position of the obese patient is changed is essential for successful intensive care.

The supine position is harmful for obese patients because the intra-abdominal pressure, when compared with non-obese patients, is excessively elevated in this position. This leads to a reduction in lung volume and, consecutively, to hypoxaemia.[66]

The intensivist must be aware that some morbidly obese patients with restricted cardiac reserve do not tolerate the supine position and are at risk of cardiac arrest. Tsueda et al.[67] have coined the term 'obesity supine death syndrome'. They reported on a 38-year-old man with morbid obesity, who died during a radiologic procedure requiring supine position. Immediately upon assuming the supine position, he became dyspnoeic and cyanotic, and developed respiratory and cardiac arrest. Resuscitation was unsuccessful.

Trendelenburg's position in obese patients is even more dangerous than supine position. Sixty-four adults (mean weight = 142 kg), who were intubated and mechanically ventilated with an FiO_2 of 0.4 were divided in two groups. Group I was maintained in supine position and group II was changed to a 15° Trendelenburg's position. The control PaO_2 in supine position was 124 ± 43 mmHg; this was less than the predicted value for non-obese patients. With change from supine to head-down position, mean PaO_2 further fell significantly to 73.0 ± 26.3 mmHg.[68] The reason for this marked decrease in PaO_2 may be an auto-transfusion of blood from the lower limbs to the pulmonary circulation and the vigorous pressure of the visceral fat masses on the diaphragm with consecutive decrease of FRC and generation of atelectases.[38] Not only in obese but also in overweight patients, hypoxaemia associated with Trendelenburg's position is an issue. Two groups, one being of normal weight (BMI 23 ± 1 kg m^{-2}), the other overweight

(BMI 27 ± 1 kg m^{-2}) were brought in Trendelenburg's position after induction of anaesthesia. In this position, overweight patients presented a significantly lower PaO_2 (164 ± 51 mmHg vs. 235 ± 27 mmHg, $p < 0.05$) than the patients with normal weight.[69] Trendelenburg's position is dangerous and should not be applied in critically ill obese patients. For application of central venous catheters, the obese patient should not be positioned in Trendelenburg's position. If a patient must be placed head down, he should be endotracheally intubated, mechanically ventilated and a continuous pulmonary and cardiocirculatory monitoring should be established.

Head-up positions, such as the 45° reverse Trendelenburg's position, the semirecumbent position, the beach-chair position or the cardiac-chair position are optimal to allow for satisfying ventilation. From a physiological point of view, it seems clear that a head-up position takes the weight of the intra-abdominal fat masses from the diaphragm; pulmonary compliance and FRC will increase. During the postoperative period, head-up positions seem to be superior to supine positions. Vaughan and Wise[70] reported that, in obese patients during the first 48 h after abdominal surgery, the semirecumbent position improved arterial oxygenation. Semirecumbent position together with supplemental oxygen is recommended for obese patients during convalescence.[38] Head-up positions, especially the 45° reverse Trendelenburg's position may facilitate weaning trials because this posture resulted in the optimal spontaneous breathing pattern with large tidal volume and low respiratory rate.[64]

Lateral decubitus position is often well tolerated in obese patients because the abdomen is relieved from the panniculus, which reduces intra-abdominal pressure and alleviates breathing. Obese subjects may develop a considerable intrinsic PEEP (PEEPi) of 4.2 ± 1.1 cmH_2O when they are lying flat. Turning into the lateral decubitus position reduced PEEPi to 2.0 ± 0.8 cmH_2O. Respiration against PEEPi contributes to an increased work of breathing, especially in supine position. Use of the lateral position offers a valid alternative.[71] Obese patients, particularly severely obese patients, however, should not lie on one side for hours because this can result in unilateral pulmonary oedema and atelectasis of the dependent lung.[72]

MV in prone position for severe lung failure in the obese poses a Herculean task for the ICU team, but it is possible and may be beneficial. An experimental study in eight mechanically ventilated pigs that were turned from supine to prone position showed that oxygenation and pulmonary gas exchange improved significantly with establishment of prone position. The improvement was more pronounced in the presence of abdominal distension.[73] There are some clinical data suggesting that turning obese patients prone may improve their pulmonary gas exchange. Data from 10 obese patients without lung injury revealed that changing from supine to prone position during MV leads to improved pulmonary function, increased FRC, better lung compliance and oxygenation.[74] There, however, exists only one case report on the use of prone position in a morbidly obese patient with lung injury.[75] After 12 h of lying prone, PaO_2/FiO_2 increased from 93 to 137 mmHg, plateau pressure decreased from 29 to 22 cmH_2O and PEEPi from 12 to 2 cmH_2O. It is of paramount importance that the position is correctly established by supporting the upper chest and pelvis without compression of vena cava or femoral veins. It must be ensured that the abdomen is allowed to hang freely.

Nutrition

Optimal nutritional support is of vital interest in critically ill obese patients. In critical illness, hypermetabolism and inflammatory response to physiologic stress affect protein, lipid and carbohydrate usage. Stress-induced hyperglycaemia is associated with higher mortality rates.[76] A nutrition plan for the obese ICU patient should always include control of blood glucose levels. Special care must be taken to avoid iatrogenic hyperglycaemia from overfeeding. In addition, obese patients exhibit increased levels of free fatty acids and triglyceride-rich adipose tissues. In critical illness, the obese patient cannot use these lipid-energy sources effectively. They catabolise relatively more protein, that is, muscle mass, and less fat compared with patients of normal weight.[77]

Hypocaloric feeding with reduced caloric load, but a high proportion of proteins, may limit hyperglycaemia, improve insulin sensitivity, prevent hypercapnia, reduce fluid retention, attenuate hypertriglyceridaemia and minimise muscle catabolism in obese patients. Weight reduction is a side effect but should never be the primary goal of nutrition during critical illness.[78] The Society of Critical Care Medicine and The American Society for Parenteral and Enteral Nutrition published guidelines for nutrition support in obese, adult, critically ill patients.[79] They recommend enteral nutrition with permissive underfeeding or hypocaloric feeding for this patient collective. For all patients with BMI > 30 kg m^{-2}, enteral nutrition should not exceed 60–70% of target energy requirements or 11–14 kcal (kg actual body weight)$^{-1}$ day^{-1}. Protein of $\geq$2.0 g (kg ideal body weight)$^{-1}$ day^{-1} should be supplied in patients with BMI of 30–40 kg m^{-2} and $\geq$2.5 g (kg ideal body weight)$^{-1}$ day^{-1} in patients with BMI ≥ 40 kg m^{-2}. Contraindications of high-protein nutrition (e.g., renal failure and hepatic encephalopathy) have to be observed. Port and Apovian[78] present an algorithm for determination of feeding needs in critically ill obese patients. They, however, advocate further investigation to validate hypocaloric, protein-rich feeding in obese patients because maintenance of excess body weight may be protective in critical illness.

Outcome of intensive-care treatment

Concerning all-cause mortality, overweight persons have a 1.2-fold increased risk to die; in obese individuals, the risk is elevated 1.5-fold when compared with persons of normal weight.[9] In critically ill patients, obesity seems to have a protective effect and is associated with a lower risk of death. This phenomenon became generally known as 'obesity paradox'. Some recent prospective observational studies have addressed this topic. Peake et al.[80] prospectively studied 493 adult patients admitted to a 14-bed medical and surgical ICU of a university affiliated hospital. They documented increasing BMI to be associated with decreasing medium- to long-term mortality. The results suggest a possible survival benefit of obesity. Ciesla et al.[41] prospectively collected data of 716 severely injured patients admitted to an ICU. Obesity was associated with prolonged ICU and hospital stay but not death. Sakr et al.[8] have reanalysed the database of the Sepsis Occurrence in Acutely Ill Patients (SOAP) study, a prospective, multicentre, observational study designed for evaluation of characteristics of ICU patients performed in 198 ICUs. The authors could not detect a significant impact of obesity on mortality; however, critically ill obese patients had prolonged ICU and hospital stays. Frat et al.[20] prospectively studied the impact of obesity in mechanically ventilated patients and observed no differences in ICU and hospital mortality rates between obese and non-obese patients.

Three large-scale meta-analyses addressed the outcome of obese ICU patients. The first meta-analysis[81] investigated 14 studies. A total of 62 045 critically ill patients, 25% ($n = 15\,347$) of them being obese (BMI ≥ 30 kg m^{-2}) were analysed. ICU mortality was not increased in the obese patient collective (relative risk (RR) $= 1.00$); however, they were longer on MV (1.5 days) and stay in the ICU was prolonged by 1.1 days. In morbidly obese patients (BMI 30–39.9 kg m^{-2}), survival rate was even higher than in non-obese patients.

A further meta-analysis[82] that investigated 23 studies (the 14 studies of the above-mentioned meta-analysis were included) confirmed the results of Akinnusi et al.,[81] and reported higher BMI associated with lower mortality. Overweight and morbidly obese patients, however, had a prolonged ICU stay.[82]

A third meta-analysis,[83] published 1 year later, analysed almost the same studies. This study reported no difference in ICU mortality, but lower hospital mortality for obese and morbidly obese subjects. No association was detected between obesity and duration of MV or length of ICU stay.[83] In summary, there is a growing body of evidence that obesity may have a protective impact on patients suffering from critical illness.

In a readable editorial, Rice[84] discussed several theories that have emerged to explain a possible survival benefit of obese patients: (1) the adipose tissue may represent a nutritional reserve attenuating the catabolism in severe illness; (2) hormones secreted by the adipocytes (leptin and interleukin-10) may have positive immunomodulatory effects; (3) during sepsis, high cholesterol and lipid levels may be beneficial by binding endotoxins; (4) outcome-improving effects of special drugs such as statins or angiotensin-converting enzyme inhibitors, which are often prescribed for obese individuals; and (5) obese patients may profit from increased clinical attention and better nurse staffing.

The mentioned studies determined the association between outcome and BMI; however, a different picture develops if the relation between outcome and fat distribution is analysed. A very recent prospective study was presented by a French working group, which reported higher death rates in obese patients with predominantly abdominal fat distribution (44% vs. 25.3%, $p < 0.01$). They determined a high sagittal abdominal diameter, and not a high BMI, to be an independent risk factor for death in critically ill patients.[85] BMI might be an inappropriate outcome determinant for obese ICU patients.

Summary

Overweight and obesity are a frequent challenge in intensive care. About 50% of the patients admitted to an ICU have a BMI above 25 kg m^{-2}. Obese patients present a bundle of pathophysiologic changes, most important being the limited pulmonary reserve and cardiovascular problems. During ICU stay, respiratory and cardiac problems have to be anticipated; also, hyperglycaemia, obstructive sleep apnoea, infections, deep vein thrombosis and decubital ulcers may complicate the course. Respiratory failure of the obese may be treated with low-tidal-volume ventilation combined with PEEP. The lungs of obese patients do not grow with increasing weight. To avoid overdistension, ideal body weight should be used for calculation of the appropriate tidal volume. Positioning the obese patient in reverse Trendelenburg's position and application of NIV immediately after extubation probably facilitates weaning from MV. Hypocaloric nutrition with a high proportion of proteins is recommended during ICU stay of obese patients to control hyperglycaemia.

Most studies in obese patients focus on anaesthesia. Concerning intensive care of these patients, there are more questions than answers. Future research has to address frequency of complications during ICU stay, role of lung protective ventilation in the obese and development of weaning protocols to allow for definition of treatment guidelines. Obesity is a heavyweight problem in the ICU – but what is consoling – is that outcome of these patients is similar to or better than that of non-obese patients.

Practice points

- Obese patients have reduced lung volumes and impaired lung mechanics.
- During ICU stay, they may suffer from several problems including respiratory problems, cardiac complications and hyperglycaemia.
- Lung protective MV with low-tidal-volumes may be feasible during respiratory failure of the obese patient.
- PEEP and lung-recruiting ventilatory strategies can counteract pulmonary atelectasis in obese patients.
- Adequate positioning is extremely important for the critically ill obese patient.
- Obese patients have similar or better outcomes than non-obese patients treated in an ICU.

Research agenda

- A prospective multicentre data collection regarding the special problems obese patients experience when treated in an ICU is missing.
- Evaluation of the question whether obese patients are at higher risk for development of respiratory failure, ALI, ARDS or sepsis than non-obese patients.
- A randomised controlled trial investigating lung protective low-tidal-volume ventilation in the obese is lacking.
- No studies exist that evaluate adequate weaning strategies in obese patients.

Conflict of interest statement

Klaus Lewandowski, MD, occasionally gives lectures in sessions sponsored by the pharmaceutical industry.

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