Obesity Surgery (2019) 29:2670–2677
https://doi.org/10.1007/s11695-019-03952-y

REVIEW ARTICLE

Obesity Surgery and Anesthesiology Risks: a Review of Key Concepts and Related Physiology

Sjaak Pouwels[1] · Marc P. Buise[2] · Pawel Twardowski[3] · Pieter S. Stepaniak[4] · Monika Proczko[5]

Published online: 24 May 2019

Abstract
The obesity epidemic is swelling to epic proportions. Obese patients often suffer from a combination of hypertension, dyslipidemia, and type 2 diabetes mellitus (T2DM), also known as the "metabolic syndrome." The metabolic syndrome is an independent predictor of cardiac dysfunction and cardiovascular disease and a risk factor for perioperative morbidity and mortality. In this paper, we discuss the perioperative risk factors and the need for advanced care of obese patients needing general anesthesia for (bariatric) surgical procedures based on physiological principles.

Keywords Bariatric surgery · Obesity · Obesity years · Cardiopulmonary physiology · Perioperative complications

Introduction

The obesity epidemic is growing to epic proportions. Obese patients need specialized equipment, special operating room (OR) tables, beds, and chairs [1].

Anesthesiologists have their specific challenges when treating obese patients, for example: (1) difficulty of venous access, (2) endotracheal intubation, (3) the risk of obesity-related comorbidity, and (4) the risk for postoperative complications.

Obese patients often suffer from a combination of hypertension, dyslipidemia, and type 2 diabetes mellitus (T2DM), also known as the "metabolic syndrome." The metabolic syndrome is an independent predictor of cardiac dysfunction and cardiovascular disease and a risk factor for perioperative morbidity and mortality. In 2015, the Association of Anaesthetists of Great Britain and Ireland Society for Obesity and Bariatric Anaesthesia published guidelines for the perioperative treatment of patients with obesity [1]. This guideline includes a recommendation for dedicated anesthesiological care for obese patients and advises making central obesity and the metabolic syndrome part of the perioperative risk stratification.

In previous papers, we described the feasibility of fast track programs for bariatric surgery [2, 3]. As the average age of the obese population continues to increase [4], all involved health care professionals must be aware of the physiological changes that occur during prolonged obesity and end-organ failure, as clinical problem-solving in terms of comorbidities and older age—which both can induce physiological changes—becomes complex.

In this paper, we will discuss several key components of the perioperative risk factors: (1) altered physiology in obesity, (2) technical difficulties in gaining adequate venous access and endotracheal intubation, and (3) the need for advanced care for patients with obesity needing general anesthesia for (bariatric) surgical procedures based on physiological principles.

Venous Access

Peripheral intravenous cannulation is necessary for the administration of fluids and medication during anesthesia. Although this procedure is straightforward and routine, peripheral intravenous access is not always easy to perform in all patients.

✉ Sjaak Pouwels
Sjaakpwls@gmail.com

[1] Department of Surgery, Haaglanden Medical Center, Lijnbaan 32, 2512 VA The Hague, The Netherlands

[2] Department of Anesthesiology, Intensive Care and Pain Medicine, Catharina Hospital, Eindhoven, The Netherlands

[3] Department of Anesthesia and Intensive Care, University Medical Center, Gdansk University, Gdansk, Poland

[4] Department of Operating Rooms, Catharina Hospital, Eindhoven, The Netherlands

[5] Department of Surgery, University Medical Center, Gdansk University, Gdansk, Poland

Successful cannulation can be influenced by various factors, such as the palpable or visual absence of a vein. Although not well described in medical literature, obesity is widely believed to be associated with difficult peripheral venous access. Ultrasound can be helpful in locating superficial peripheral veins in patients with an increased body mass [1]. However, a recent Scandinavian study shows that 85% of the first attempts for venous cannulation proved successful [5].

Endotracheal Intubation

Obesity is commonly perceived to be a risk factor for difficult endotracheal intubation, being associated with a 30% increased risk for difficulties, although predictors for difficult laryngoscopy are similar in the normal population [6]. The unanticipated problematic airway places patients at an increased risk of adverse outcomes. In a recent French observational multicenter study, a cohort of 12,500 patients, of which 20% was obese, was followed during their stay in operation room (OR) or intensive care unit (ICU) [7]. In the OR, the incidence of difficult intubation was 8.2% versus 16.3% in the ICU. Risk factors for difficult intubation were the Mallampati score III/IV, obstructive sleep apnea syndrome, and reduced mobility of the cervical spine in both ICU and OR. Special risk factors in the ICU were: (1) limited mouth opening, (2) severe hypoxemia, and (3) coma. In a large-scale British audit project, the proportion of major complications following primary airway problems related to tracheal intubation was similar in obese and non-obese patients [8].

Difficulties in airway management decrease after providing optimal preoxygenation and ramped positioning. For patients with obesity, proper positioning of the patient forms 90% of the preparation for proper airway management [9]. Additionally, the use of alternative airway devices (video laryngoscope) reduces failed endotracheal intubation [10].

Obstructive Sleep Apnea and Perioperative Care

Obstructive sleep apnea syndrome (OSAS) is common in the obese population. Patients with BMI > 35 kg/m^2 have an incidence of almost 20% of severe OSA [1]. OSA is often undiagnosed but is associated with higher postoperative desaturation, respiratory failure, and cardiac adverse events [11].

Some of the cardiopulmonary changes caused by obesity are associated with OSAS and obesity hypoventilation syndrome (OHS). OHS is characterized by chronic hypoxia, hypercapnia, and respiratory acidosis [12]. These chronic hypoxia and hypercapnia result mainly in pulmonary vasoconstriction [12]. The presence of high pre-existing pulmonary blood flow in conjunction with pulmonary vasoconstriction leads to pulmonary hypertension and a significant transpulmonary diastolic pressure gradient in addition to elevated left ventricular filling pressures [12, 13]. Patients with OSAS have an increased risk of developing AF, even without underlying cardiac disease, and in obese cohorts, the prevalence of OSAS can extend to up to 90% [14]. The Sleep Heart Study demonstrated that the risk of AF is four times greater in patients with sleep-disordered breathing (obstructive and central sleep apnea) compared with patients with no sleep-disordered breathing [15]. Patients with OHS exhibit a lowered neuromuscular response to hypercapnia and hypoxemia, caused by a blunted central drive [16–20]. It is unclear what causes this blunted central drive.

Animal research showed that nocturnal hypoxemia lowers the hypoxic ventilatory drive and raises the arousal threshold, possibly due to an effect on the synthesis and turnover of neurotransmitters [19, 21–24]. Because of this, patients fail to compensate adequately after an episode of hypoventilation, leading to decreased ventilation in between episodes for a given CO_2 load, combined with a relatively shorter time span between episodes considering the duration of apneic episodes [21, 23, 24]. Norman et al. [25] hypothesize that repeated nocturnal CO_2 accumulations cause bicarbonate retention by the kidneys. Most patients have enough time to compensate for this brief rise in CO_2. If this does not occur, chronic bicarbonate retention develops and the threshold for hypercapnia rises [19, 25]. The cause(s) of this diminished response have yet to be discovered. Possible factors include leptin and IL-GF-1 due to their stimulating effect on the central respiratory centers [19]. Hypoxia and hypercapnia affect sympathetic nerve activity and cause vasoconstriction, which will result in hypertension. This is a risk factor for developing AF [26, 27]. The severity of OSAS, indicated by the number of nocturnal desaturations, correlates with the prevalence of AF [28] and predicts AF within approximately 5 years of OSAS being diagnosed [29].

To identify patients with OSA, questionnaires like the STOP-Bang can be used. One study shows that the STOP-Bang has a poor correlation with postoperative OSAS [30]. In fast-track bariatric surgery, the importance of OSAS seems to be reduced. In 2009, we reported a scheduled ICU stay of one night in 5.2% of all patients to avoid respiratory failure due to OSAS [31]. After introducing the “fast track” clinical pathway, this ICU stay was only planned on comorbidity and showed overall lower complication rates [2, 3].

Cardiovascular Physiology

Cardiac Remodeling

Obesity induces blood volume changes that can result in right and/or left heart failure [12]. Basically, the pathophysiological mechanism is multifactorial. With moderate or severe obesity, significant increments in blood volume are found, and this accompanied an increase in cardiac output [12]. Results from

inert gas washout studies showed that excess body fat incorporates an extra blood flow of 2–3 mL/min/100 g. This means that 100 kg of excess body fat would require as much as 3 L/min blood flow [12]. Actually, the blood volume and cardiac output of an individual weighing 170 kg are roughly twice than those of a subject weighing 70 kg [12]. Resting heart rate is often similar between obese and non-patients, which implies an increased stroke volume [32–34]. A significantly larger stroke volume and cardiac output are observed [32, 33], or a rising trend [34].

One of the components of the metabolic syndrome is systemic hypertension. Hypertension is the result of obesity-induced structural and functional adaptations of the cardiovascular system as well as of adipokine effects on inflammation and vascular homeostasis [35].

Chronic volume overload (preload) in combination with hypertension (afterload) leads to compensatory mechanisms like left ventricular enlargement and hypertrophy. It has been observed that the left ventricle dilates in obese patients resulting in increased diastolic and systolic volumes compared with that in non-obese patients [36]. On the other hand, there are also reports suggesting that obesity is frequently associated with concentric remodeling (2.6–74%). By definition, left ventricular mass is normal, while both wall thickness and relative wall thickness are increased [37]. Obesity results in augmented left ventricular preload and often afterload, with maintenance of a high output state at the expense of elevated right and left ventricular filling pressures [12, 13]. Diastolic dysfunction is quite common in obese patients [13, 32, 38, 39], which is probably related to the higher incidence of LVH.

As usual, the right ventricular (RV) function has received much less attention than the function of the left ventricle. OSA and OHS lead to pulmonary vascular changes. OHS is characterized by chronic hypoxia, hypercapnia, and respiratory acidosis [12]. This chronic hypoxia and hypercapnia result mainly in pulmonary vasoconstriction [12]. The presence of high pre-existing pulmonary blood flow in conjunction with pulmonary vasoconstriction leads to pulmonary hypertension and a significant transpulmonary diastolic pressure gradient in addition to elevated left ventricular filling pressures [12, 13]. This results in right cardiac hypertrophy and finally in right cardiac failure (pulmonary heart disease) [32].

Atrial Fibrillation and Anticoagulants

The link between obesity and atrial fibrillation (AF) was first acknowledged after a retrospective analysis of the incidence of AF in perioperative cardiac surgical patients. A significant amount of evidence shows a relationship between obesity and AF [29, 40–64]. Patients with obesity have a 50% increased risk for AF compared with non-obese patients [40, 41]. Wang et al. [40] showed that there is a 4% increase in risk for AF per 1 unit increase in BMI. This risk was calculated after a mean follow-up of 13.7 years [40]. The Danish Diet, Cancer and Health Study showed an even higher risk of AF associated with the increase in anthropometric variables like height, weight, hip and waist circumference, and with an increase in body fat mass/percentage and lean body mass [43]. Schmidt et al. reported that overweight and obese young men have a twofold risk of AF compared with non-obese patients [52], despite the low incidence of cardiac arrhythmias in this specific age group [48]. Additionally, specific hormonal profiles in patients with obesity correlate with the occurrence of AF [54]. One of these hormones is resistin, which is mainly secreted from lipid cells and is linked to both T2DM and obesity. The increased level of resistin in obese patients seems to be correlated with paroxysmal and persistent AF [54]. Several studies report that obesity independently predicts the progression from paroxysmal to permanent AF [58–60]. Sandhu et al. [59] showed that in women with AF at baseline, increasing BMI was associated with the early development of non-paroxysmal AF. Also, in patients whose initial AF episode terminates, weight loss might be beneficial, giving a lower risk for the future development of permanent AF [60]. A study by Guglin et al. [61] demonstrated that obesity is associated with a higher recurrence rate of AF compared with that of non-obese patients [61]. Additionally, the size of the left atrium was found to be an independent predicting factor of recurrence and AF burden. A meta-analysis of Guijian et al. [62] reported that an elevated BMI is significantly associated with AF recurrence after pulmonary vein isolation. Patients with obesity after cardiothoracic surgery also have a higher risk of developing AF compared with non-obese patients [55, 56] and this risk increases with an increased BMI [56]. However, the type of surgery does not seem to affect this risk [57].

Patients with AF often use oral anticoagulants to prevent possible future thromboembolic events. Comorbidities like hypertension and T2DM are part of the risk stratification for thromboembolic events (CHA2DS2-VASc score). Obesity is a complicating factor regarding the correct dosing of both the classic anticoagulants—vitamin K antagonist—and the direct oral anticoagulants (DOAC). The perioperative bridging of oral anticoagulants with heparin or low-molecular-weight heparin presents a challenge [65].

A recent study by Schijns et al. [66] showed that adequately dosing postoperative thrombosis prophylaxis is of utmost importance. In their study, after undergoing the Roux-en-Y gastric bypass, patients with a total body weight (TBW) higher than 140 kg received postoperative thrombosis prophylaxis (nadroparin 5700 IU for 4 weeks). After the last nadroparin administration, the anti-Xa activity was measured. The mean anti-Xa activity following 5700 IU nadroparin was 0.19 ± 0.07 IU/mL. Of all patients, 32% had anti-Xa levels below the prophylactic range. Anti-Xa

activity inversely correlated with TBW (correlation coefficient -− 0.410) and lean body weight (LBW; correlation coefficient − 0.447); 67% of patients with a LBW ≥ 80 kg had insufficient anti-Xa activity concentrations. Especially in patients with LBW ≥ 80 kg, a higher dose may potentially be required to reach adequate prophylactic anti-Xa levels. Despite these aspects, the incidence of thromboembolic events (like deep vein thrombosis or pulmonary embolisms) varies between 0.3 and 1.0%, according to a recent study by Thereaux et al. [67].

Pulmonary Physiology

Van Huisstede [68] investigated the relationship between pulmonary function and the risk of postoperative complications in 485 patients. A total of 53 complications were found, of which eight were pulmonary. Significantly lower FEV1 (mean 86.9% of predicted) and FVC (mean 95.6% of predicted) (both $p < 0.05$) were found in patients with complications compared with patients without [42]. A FEV1/FVC < 70% and a δFEV1 ≥ 12% were found to be significant independent predictors for pulmonary complications [68].

Physiologically, obesity is associated with an altered lung function. This is characterized by a reduction of lung volumes, mostly a restrictive pattern. The pathogenesis is multifactorial, with one of the possible mechanisms being an increased truncal fat load [69].

Because of affected respiratory physiological parameters such as compliance, neuromuscular strength, work of breathing lung volumes, and spirometric measurements [20, 70], obese subjects are prone to develop pulmonary complications after bariatric surgery. Several strategies are present to improve perioperative care, such as early detubation and protective ventilation strategies as well as the introduction of fast-track anesthesia protocols [2, 3]. Optimal perioperative care needs to be evaluated on a case-to-case basis. Regarding the link between the impaired lung function, postoperative complications, and the necessity of pulmonary function screening prior to bariatric surgery, conflicting results exist and future studies need to determine whether preoperative pulmonary function screening is useful in bariatric practice.

The Obesity Paradox and Its Mechanisms

Obesity plays a significant role in the development of cardiovascular and pulmonary diseases. The term "obesity paradox" refers to the observation that when acute cardiovascular decompensation occurs in myocardial infarction or congestive heart failure, obese patients may have a survival benefit. In addition, it is suggested that obese patients tend to fare better after certain surgical procedures, such as coronary artery bypass surgery [71, 72].

The complex relationship between obesity and various cardiovascular diseases is difficult to understand. Potential mechanisms are [71, 72] inadequate weight loss, differences in metabolic reserve, less cachexia, protective cytokines, differences in the activity of the renin-angiotensin-aldosterone system (RAAS), and various causes of heart failure. Also, anthropometric variables such as BMI and waist-to-hip ratio may be inaccurate to assess true body fatness [71–73]. Besides the traditional risk factors (e.g., high blood pressure, lipids, and glucose) for developing cardiovascular diseases, genetic factors may be implicated in metabolically healthy obese patients (without comorbidities) versus metabolic unhealthy obese patients (with comorbidities) [71–73]. Although the duration of obesity also seems to matter, we are currently unable to adequately assess the risks of prolonged "exposure" to obesity [74]. Finally, the use of certain medication must be considered in the obesity paradox. One example is the treatment with statins. In many studies, patients treated with statins have a lower long-term mortality than those who are not treated with statins [72, 73].

Assessing the Burden of Obesity

Most risk factors for postoperative complications are the result of the metabolic syndrome due to obesity. BMI itself is a risk factor but comorbidities develop over time [75]. The mean duration of obesity is a significant factor for left and/or right ventricular failure [76]. To make the relation between time, duration, and obesity more implicit, there is a need for an assessment method that shows the burden of obesity and the development of comorbidities at an individual level. Perhaps a term similar to pack-years (used to assess the burden of smoking) is needed to give us more insight. We would, therefore, like to introduce the term "fat-years." Although there is currently no such marker for obesity in its timeline, there is an indication that older patients get more cardiopulmonary morbidity due to obesity and/or metabolic syndrome, which in turn can create a potential perioperative risk [31, 75, 77]. After becoming more familiar with this term, healthcare professionals working with obese patients will likely become more conscious of the risk in the older (55–60 years old) obese group than is the case for younger patients. A recent letter [4] shows that there is a shift from younger to older patients that seek bariatric surgery. Secondly, despite claims that obesity is less harmful in older individuals, the absolute rise in mortality rates associated with a higher BMI is still much greater in elderly subjects [78]. According to these studies, there is an increasing

need for adequate risk assessment in bariatric surgical patients.

How to Perform Adequate Screening

Two questions arise then. First, do we need to screen obese patients scheduled for bariatric surgery to identify potential postoperative complications? With regard to pulmonary complications, several studies have been done. However, the Holy Grail has yet to be found. Second, do we need to screen obese patients for the presence of obstructive sleep apnea syndrome (OSAS) [19, 79]? This is because OSAS frequently occurs untreated and might lead to postoperative complications [80–83].

Current literature regarding the relationship between an impaired pulmonary function and the occurrence of postoperative complications is sparse. In a study performed by Farina et al. [84], the value of spirometry as a preoperative screening tool was investigated. This was used to identify patients at risk for postoperative pulmonary complications (PPC), scheduled for open bileopancreatic diversion surgery. They found a complication rate of 7.5% in patients with suspected restrictive pulmonary impairment [84]. Hamoui et al. [85] found that a decreased VC ($p = 0.0007$) was a significant predictor for PPCs [85]. In contrast to these results, Catheline et al. [86] found that preoperative pulmonary abnormalities had no consequences for the management of the perioperative period in bariatric surgical patients.

There is no consensus regarding whether patients scheduled for bariatric surgery need to be screened for OSAS. The additive value of screening for sleep apnea prior to laparoscopic bariatric surgery for predicting PPCs is questionable according to the study by Nepomnayshy et al. [87]. The study by Peromaa-Haavisto et al. [88] showed that in a population of 197 obese patients scheduled for bariatric surgery, the prevalence of OSAS was 71%, with a significantly higher prevalence in males (90%) than in females (60%). Their study results recommend OSAS screening preoperatively especially in obese men [88].

Conclusion

Based on current literature, there is enough evidence that patients with obesity have an altered cardiopulmonary function and a higher risk for developing postoperative complications after bariatric surgery. Unfortunately, there is no consensus as to why, how, and when to screen obese patients. Based on current literature, we might conclude that a high BMI is not the only explanation. Factors like age and the duration of obesity need also to be taken into account. Although no adequate assessment tool exists to identify these patients, there is an increasing need for a scoring system that assesses the "burden" of obesity. Such a tool might be helpful in identifying patients prone to postoperative complications.

Contributions Initial idea and design of the study: SP, MB, PT, PS, and MP
Drafting and finalizing the manuscript: SP, MB, PT, PS, and MP
Final approval: SP, MB, PT, PS, and MP

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval Statement For this type of study, formal consent is not required.

Informed Consent Statement Does not apply.

References

1. Nightingale CE, Margarson MP, Shearer E, et al. Peri-operative management of the obese surgical patient 2015: Association of Anaesthetists of Great Britain and Ireland Society for Obesity and Bariatric Anaesthesia. Anaesthesia. 2015;70(7):859–76.
2. Vreeswijk SJ, van Rutte PW, Nienhuijs SW, et al. The safety and efficiency of a fast-track protocol for sleeve gastrectomy: a team approach. Minerva Anestesiol. 2018;84(8):898–906.
3. van Wezenbeek MR, Pouwels S, Buise MP, et al. Conventional versus fast track anaesthesia in an unselected group of patients undergoing revisional bariatric surgery. International Journal of Surgery Open. 2015;1:22–7.
4. Versteegden DPA, Buise MP, Nienhuijs SW. Shift towards older bariatric patients. Obes Surg. 2018;28(2):555–6.
5. Brandt HG, Jepsen CH, Hendriksen OM, et al. The use of ultrasound to identify veins for peripheral venous access in morbidly obese patients. Dan Med J. 2016;63(2)
6. Lundstrom LH, Moller AM, Rosenstock C, et al. 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. 2009;110(2):266–74.
7. De Jong A, Molinari N, Pouzeratte Y, et al. Difficult intubation in obese patients: incidence, risk factors, and complications in the operating theatre and in intensive care units. Br J Anaesth. 2015;114(2):297–306.
8. Cook TM, Woodall N, Frerk C. 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. Br J Anaesth. 2011;106(5):617–31.
9. Dixon DR, Braude D. THE BARIATRIC AIRWAY. It's not all about the intubation. JEMS 2015;40(8):58–60.
10. Aceto P, Perilli V, Modesti C, et al. Airway management in obese patients. Surg Obes Relat Dis : Off J Am Soc Bariatric Surg. 2013;9(5):809–15.
11. Mutter TC, Chateau D, Moffatt M, et al. A matched cohort study of postoperative outcomes in obstructive sleep apnea: could

preoperative diagnosis and treatment prevent complications? Anesthesiology. 2014;121(4):707–18.
12. Alexander JK. The cardiomyopathy of obesity. Prog Cardiovasc Dis. 1985;27(5):325–34.
13. Alpert MA, Terry BE, Kelly DL. Effect of weight loss on cardiac chamber size, wall thickness and left ventricular function in morbid obesity. Am J Cardiol. 1985;55(6):783–6.
14. Frey WC, Pilcher J. Obstructive sleep-related breathing disorders in patients evaluated for bariatric surgery. Obes Surg. 2003;13(5):676–83.
15. Mehra R, Benjamin EJ, Shahar E, et al. Association of nocturnal arrhythmias with sleep-disordered breathing: The Sleep Heart Health Study. Am J Respir Crit Care Med. 2006;173(8):910–6.
16. Chlif M, Keochkerian D, Choquet D, et al. Effects of obesity on breathing pattern, ventilatory neural drive and mechanics. Respir Physiol Neurobiol. 2009;168(3):198–202.
17. Chlif M, Keochkerian D, Feki Y, et al. Inspiratory muscle activity during incremental exercise in obese men. Int J Obes (Lond). 2007;31(9):1456–63.
18. Chlif M, Keochkerian D, Mourlhon C, et al. Noninvasive assessment of the tension-time index of inspiratory muscles at rest in obese male subjects. Int J Obes (Lond). 2005;29(12):1478–83.
19. Lin CK, Lin CC. Work of breathing and respiratory drive in obesity. Respirology (Carlton, Vic). 2012;17(3):402–11.
20. Sood A. Altered resting and exercise respiratory physiology in obesity. Clin Chest Med. 2009;30(3):445–54, vii
21. Hlavac MC, Catcheside PG, McDonald R, et al. Hypoxia impairs the arousal response to external resistive loading and airway occlusion during sleep. Sleep. 2006;29(5):624–31.
22. Yang AL, Lo MJ, Ting H, et al. GABA(A) and GABA(B) receptors differentially modulate volume and frequency in ventilatory compensation in obese Zucker rats. J Appl Physiol(Bethesda, Md : 1985). 2007;102(1):350–7.
23. Lee SD, Nakano H, Farkas GA. Adenosinergic modulation of ventilation in obese zucker rats. Obes Res. 2005;13(3):545–55.
24. Nakano H, Lee SD, Farkas GA. Dopaminergic modulation of ventilation in obese Zucker rats. J Appl Physiol (Bethesda, Md : 1985). 2002;92(1):25–32.
25. Norman RG, Goldring RM, Clain JM, et al. Transition from acute to chronic hypercapnia in patients with periodic breathing: predictions from a computer model. J Appl Physiol(Bethesda, Md : 1985). 2006;100(5):1733–41.
26. Somers VK, White DP, Amin R, et al. Sleep apnea and cardiovascular disease: an American Heart Association/American College Of Cardiology Foundation Scientific Statement from the American Heart Association Council for High Blood Pressure Research Professional Education Committee, Council on Clinical Cardiology, Stroke Council, and Council On Cardiovascular Nursing. In collaboration with the National Heart, Lung, and Blood Institute National Center on Sleep Disorders Research (National Institutes of Health). Circulation. 2008;118(10):1080–111.
27. Camm AJ, Kirchhof P, Lip GY, et al. Guidelines for the management of atrial fibrillation: the Task Force for the Management of Atrial Fibrillation of the European Society of Cardiology ESC. Europace. 2010;12(10):1360–420.
28. Tanigawa T, Yamagishi K, Sakurai S, et al. Arterial oxygen desaturation during sleep and atrial fibrillation. Heart. 2006;92(12):1854–5.
29. Gami AS, Hodge DO, Herges RM, et al. Obstructive sleep apnea, obesity, and the risk of incident atrial fibrillation. J Am Coll Cardiol. 2007;49(5):565–71.
30. Schumann R, Kwater AP, Bonney I, et al. Respiratory volume monitoring in an obese surgical population and the prediction of postoperative respiratory depression by the STOP-bang OSA risk score. J Clin Anesth. 2016;34:295–301.
31. van den Broek RJ, Buise MP, van Dielen FM, et al. Characteristics and outcome of patients admitted to the ICU following bariatric surgery. Obes Surg. 2009;19(5):560–4.
32. Rider OJ, Francis JM, Ali MK, et al. Beneficial cardiovascular effects of bariatric surgical and dietary weight loss in obesity. J Am Coll Cardiol. 2009;54(8):718–26.
33. Karason K, Wallentin I, Larsson B, et al. Effects of obesity and weight loss on cardiac function and valvular performance. Obes Res. 1998;6(6):422–9.
34. Kardassis D, Bech-Hanssen O, Schonander M, et al. Impact of body composition, fat distribution and sustained weight loss on cardiac function in obesity. Int J Cardiol. 2012;159(2):128–33.
35. Koliaki C, Liatis S, Kokkinos A. Obesity and cardiovascular disease: revisiting an old relationship. Metabolism: clinical and experimental. 2018.
36. Aggarwal R, Harling L, Efthimiou E, et al. The effects of bariatric surgery on cardiac structure and function: a systematic review of cardiac imaging outcomes. Obes Surg. 2015;
37. Lang RM. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Eur Heart J Cardiovasc Imaging. 2015;16(2):233–70.
38. Martin J, Bergeron S, Pibarot P, et al. Impact of bariatric surgery on N-terminal fragment of the prohormone brain natriuretic peptide and left ventricular diastolic function. Can J Cardiol. 2013;29(8):969–75.
39. Leichman JG, Wilson EB, Scarborough T, et al. Dramatic reversal of derangements in muscle metabolism and left ventricular function after bariatric surgery. Am J Med. 2008;121(11):966–73.
40. Wang TJ, Parise H, Levy D, et al. Obesity and the risk of new-onset atrial fibrillation. Jama. 2004;292(20):2471–7.
41. Wanahita N, Messerli FH, Bangalore S, et al. Atrial fibrillation and obesity–results of a meta-analysis. Am Heart J. 2008;155(2):310–5.
42. Verdecchia P, Dagenais G, Healey J, et al. Blood pressure and other determinants of new-onset atrial fibrillation in patients at high cardiovascular risk in the Ongoing Telmisartan Alone And In Combination with Ramipril Global Endpoint Trial/Telmisartan Randomized Assessment Study in ACE iNtolerant subjects with cardiovascular disease studies. J Hypertens. 2012;30(5):1004–14.
43. Frost L, Benjamin EJ, Fenger-Gron M, et al. Body fat, body fat distribution, lean body mass and atrial fibrillation and flutter. A Danish cohort study. Obesity (Silver Spring, Md). 2014;22(6):1546–52.
44. Murphy NF, MacIntyre K, Stewart S, et al. Long-term cardiovascular consequences of obesity: 20-year follow-up of more than 15 000 middle-aged men and women (the Renfrew-Paisley study). Eur Heart J. 2006;27(1):96–106.
45. Wilhelmsen L, Rosengren A, Lappas G. Hospitalizations for atrial fibrillation in the general male population: morbidity and risk factors. J Intern Med. 2001;250(5):382–9.
46. Rosengren A, Hauptman PJ, Lappas G, et al. Big men and atrial fibrillation: effects of body size and weight gain on risk of atrial fibrillation in men. Eur Heart J. 2009;30(9):1113–20.
47. Tedrow UB, Conen D, Ridker PM, et al. The long- and short-term impact of elevated body mass index on the risk of new atrial fibrillation the WHS (women's health study). J Am Coll Cardiol. 2010;55(21):2319–27.
48. Karasoy D, Bo Jensen T, Hansen ML, et al. Obesity is a risk factor for atrial fibrillation among fertile young women: a nationwide cohort study. Europace : European pacing, arrhythmias, and cardiac electrophysiology : journal of the working groups on cardiac

pacing, arrhythmias, and cardiac cellular electrophysiology of the European Society of Cardiology. 2013;15(6):781–6.
49. Tanner RM, Baber U, Carson AP, et al. Association of the metabolic syndrome with atrial fibrillation among United States adults (from the REasons for Geographic and Racial Differences in Stroke [REGARDS] Study). Am J Cardiol. 2011;108(2):227–32.
50. Chamberlain AM, Agarwal SK, Ambrose M, et al. Metabolic syndrome and incidence of atrial fibrillation among blacks and whites in the Atherosclerosis Risk in Communities (ARIC) Study. Am Heart J. 2010;159(5):850–6.
51. Miyasaka Y, Barnes ME, Gersh BJ, et al. Secular trends in incidence of atrial fibrillation in Olmsted County, Minnesota, 1980 to 2000, and implications on the projections for future prevalence. Circulation. 2006;114(2):119–25.
52. Schmidt M, Botker HE, Pedersen L, et al. Comparison of the frequency of atrial fibrillation in young obese versus young nonobese men undergoing examination for fitness for military service. Am J Cardiol. 2014;113(5):822–6.
53. Knuiman M, Briffa T, Divitini M, et al. A cohort study examination of established and emerging risk factors for atrial fibrillation: the Busselton Health Study. Eur J Epidemiol. 2014;29(3):181–90.
54. Ozcan KS, Gungor B, Altay S, et al. Increased level of resistin predicts development of atrial fibrillation. J Cardiol. 2014;63(4):308–12.
55. Echahidi N, Mohty D, Pibarot P, et al. Obesity and metabolic syndrome are independent risk factors for atrial fibrillation after coronary artery bypass graft surgery. Circulation. 2007;116(11 Suppl):I213–9.
56. Zacharias A, Schwann TA, Riordan CJ, et al. Obesity and risk of new-onset atrial fibrillation after cardiac surgery. Circulation. 2005;112(21):3247–55.
57. Hernandez AV, Kaw R, Pasupuleti V, et al. Association between obesity and postoperative atrial fibrillation in patients undergoing cardiac operations: a systematic review and meta-analysis. Ann Thorac Surg. 2013;96(3):1104–16.
58. Tsang TS, Barnes ME, Miyasaka Y, et al. Obesity as a risk factor for the progression of paroxysmal to permanent atrial fibrillation: a longitudinal cohort study of 21 years. Eur Heart J. 2008;29(18):2227–33.
59. Sandhu RK, Conen D, Tedrow UB, et al. Predisposing factors associated with development of persistent compared with paroxysmal atrial fibrillation. J Am Heart Assoc. 2014;3(3):e000916.
60. Thacker EL, McKnight B, Psaty BM, et al. Association of body mass index, diabetes, hypertension, and blood pressure levels with risk of permanent atrial fibrillation. J Gen Intern Med. 2013;28(2):247–53.
61. Guglin M, Maradia K, Chen R, et al. Relation of obesity to recurrence rate and burden of atrial fibrillation. Am J Cardiol. 2011;107(4):579–82.
62. Guijian L, Jinchuan Y, Rongzeng D, et al. Impact of body mass index on atrial fibrillation recurrence: a meta-analysis of observational studies. Pacing Clin Electrophysiol: PACE. 2013;36(6):748–56.
63. Schnabel RB, Aspelund T, Li G, et al. Validation of an atrial fibrillation risk algorithm in whites and African Americans. Arch Intern Med. 2010;170(21):1909–17.
64. Schnabel RB, Sullivan LM, Levy D, Pencina MJ, Massaro JM, D'Agostino RB, Sr., Newton-Cheh C, Yamamoto JF, Magnani JW, Tadros TM, Kannel WB, Wang TJ, Ellinor PT, Wolf PA, Vasan RS, Benjamin EJ Development of a risk score for atrial fibrillation (Framingham Heart Study): a community-based cohort study. Lancet (London, England) 2009;373(9665):739–745.
65. George-Phillips KL, Bungard TJ. Use of low-molecular-weight heparin to bridge therapy in obese patients and in patients with renal dysfunction. Pharmacotherapy. 2006;26(10):1479–90.
66. Schijns W, Deenen MJ, Aarts EO, et al. The effect of obesity on anti-Xa concentrations in bariatric patients. Obes Surg. 2018;28(7):1997–2005.
67. Thereaux J, Lesuffleur T, Czernichow S, et al. To what extent does posthospital discharge chemoprophylaxis prevent venous thromboembolism after bariatric surgery?: results from a nationwide cohort of more than 110,000 patients. Ann Surg. 2018;267(4):727–33.
68. van Huisstede A, Biter LU, Luitwieler R, et al. Pulmonary function testing and complications of laparoscopic bariatric surgery. Obes Surg. 2013;23(10):1596–603.
69. Watson RA, Pride NB, Thomas EL, et al. Relation between trunk fat volume and reduction of total lung capacity in obese men. J Appl Physiol(Bethesda, Md : 1985). 2012;112(1):118–26.
70. Pedoto A. Lung physiology and obesity: anesthetic implications for thoracic procedures. Anesthesiol Res Pract. 2012;2012:154208.
71. Lavie CJ, De Schutter A, Parto P, et al. Obesity and prevalence of cardiovascular diseases and prognosis-the obesity paradox updated. Prog Cardiovasc Dis. 2016;58(5):537–47.
72. Lavie CJ, Milani RV, Ventura HO. Obesity and cardiovascular disease: risk factor, paradox, and impact of weight loss. J Am Coll Cardiol. 2009;53(21):1925–32.
73. Lee GK, Cha YM. Cardiovascular benefits of bariatric surgery. Trends Cardiovasc Med. 2016;26(3):280–9.
74. Alpert MA, Lambert CR, Panayiotou H, et al. Relation of duration of morbid obesity to left ventricular mass, systolic function, and diastolic filling, and effect of weight loss. Am J Cardiol. 1995;76(16):1194–7.
75. Flegal KM, Kit BK, Orpana H, et al. Association of all-cause mortality with overweight and obesity using standard body mass index categories: a systematic review and meta-analysis. Jama. 2013;309(1):71–82.
76. Alpert MA, Terry BE, Mulekar M, et al. Cardiac morphology and left ventricular function in normotensive morbidly obese patients with and without congestive heart failure, and effect of weight loss. Am J Cardiol. 1997;80(6):736–40.
77. Buise MP, van den Broek RJC, de Zoete JP, et al. Advanced care admission following bariatric surgery. Neth J Crit Care. 2010;14(2):85–91.
78. Osher E, Stern N. Obesity in elderly subjects: in sheep's clothing perhaps, but still a wolf! Diabetes Care. 2009;32(Suppl 2):S398–402.
79. Piper AJ, Grunstein RR. Big breathing: the complex interaction of obesity, hypoventilation, weight loss, and respiratory function. J Appl Physiol(Bethesda, Md : 1985). 2010;108(1):199–205.
80. Chung F, Abdullah HR, Liao P. STOP-Bang questionnaire: a practical approach to screen for obstructive sleep apnea. Chest. 2015;
81. Chung F, Yang Y, Liao P. Predictive performance of the STOP-bang score for identifying obstructive sleep apnea in obese patients. Obes Surg. 2013;23(12):2050–7.
82. Chung F, Yegneswaran B, Liao P, et al. STOP questionnaire: a tool to screen patients for obstructive sleep apnea. Anesthesiology. 2008;108(5):812–21.
83. Proczko MA, Stepaniak PS, de Quelerij M, et al. STOP-Bang and the effect on patient outcome and length of hospital stay when patients are not using continuous positive airway pressure. J Anesth. 2014;28(6):891–7.
84. Farina A, Crimi E, Accogli S, et al. Preoperative assessment of respiratory function in severely obese patients undergoing biliopancreatic diversion. Eur Surg Res. 2012;48(2):106–10.
85. Hamoui N, Anthone G, Crookes PF. The value of pulmonary function testing prior to bariatric surgery. Obes Surg. 2006;16(12):1570–3.

86. Catheline JM, Bihan H, Le Quang T, et al. Preoperative cardiac and pulmonary assessment in bariatric surgery. Obes Surg. 2008;18(3):271–7.
87. Nepomnayshy D, Hesham W, Erickson B, et al. Sleep apnea: is routine preoperative screening necessary? Obes Surg. 2013;23(3):287–91.
88. Peromaa-Haavisto P, Tuomilehto H, Kossi J, et al. Prevalence of obstructive sleep apnoea among patients admitted for bariatric surgery. A prospective multicentre trial. Obes Surg. 2015;