A single tertiary centre outlook on the short-term outcome of bariatric surgery in improving pulmonary parameters and sleep apnoea

Ahmad Adib Bin Mohd Nasir¹, Andrea Yu-Lin Ban¹, Syed Zulkifli Syed Zakaria², Nik Ritza Kosai Nik Mahmood³ and Mohamed Faisal Abdul Hamid¹

Abstract
Background: Obesity is associated with obstructive sleep apnoea (OSA). Weight loss is an effective treatment. Bariatric surgery for obese, symptomatic OSA patients results in weight loss and improvement in lung function and sleep apnoea. This study aimed to determine the effectiveness of bariatric surgery in improving the respiratory mechanics and sleep apnoea using a lung function test and sleep study.

Methods: A prospective study was conducted at the Pusat Perubatan Universiti Kebangsaan Malaysia Medical Centre involving adults undergoing bariatric work-up, attending respiratory clinic or admitted for bariatric work-up. We included subjects with a body mass index (BMI) >35 kg/m² and Apnoea–Hypopnoea Index (AHI) of >5 events/hour. Subjects were assessed at baseline and at 12±2 weeks post bariatric surgery using the following methods: a partial sleep study, lung function test, six-minute walk test (6MWT) and Epworth Sleepiness Scale (ESS) score.

Results: Twelve subjects were analysed. Their mean age was 36±5.7 years, and eight (67%) were female. The baseline mean AHI was 24.75±9.51 events/hour, the nadir mean oxygen saturation during sleep (SpO₂) was 83.6±3.8%, the mean ESS score was 16±4, the mean forced expiratory volume in one second (FEV₁) was 2.66±0.35 L, the mean forced vital capacity (FVC) was 3.23±0.45 L, the mean total lung capacity (TLC) was 4.97±1.19 L, the mean expiratory reserve volume (ERV) was 0.5±0.46 L, the mean residual volume (RV) was 1.46±0.91 L, the mean adjusted diffusing lung capacity for carbon monoxide (DLCO Adj) was 22.71±5.22 mL/mmHg/min, the mean adjusted diffusing lung capacity corrected for alveolar volume (DLVA Adj) was 5.61±0.90 mL/mmHg/min and the mean 6MWT was 293±49 m. Post surgery (12±2 weeks), the mean BMI decreased from 45.5 kg/m² to 39.7 kg/m², with a clinically significant improvement in AHI, ESS score, nadir SpO₂, FEV₁, FVC, TLC, ERV, RV, DLCO Adj, DLVA Adj and 6MWT (p<0.05).

Conclusion: Bariatric surgery improves sleep apnoea and lung function and reduces daytime somnolence.

Keywords
Bariatric surgery, lung function test, obesity, sleep apnoea

Introduction
Obesity is a recognised global epidemic and public health concern.1 The prevalence of obesity has increased almost threefold in the past three decades.2 The obesity rate in Malaysia is three to four times higher than other Asian countries.3 The National Health and Morbidity Surveys (NHMSs) done in 1996, 2006, 2011 and 2015 showed an increasing trend of obesity in adult Malaysians from 4.0% to 17.7%.4,5

Obesity affects the respiratory mechanics. With increasing body weight, lung volume is reduced,6 causing dyspnoea in up to 80% of obese patients. The decrease in lung volume is reflected
The inclusion criteria were adults aged ≥18 years attending a bariatric work-up clinic or respiratory clinic or admitted for bariatric surgery work-up with morbid obesity (i.e. a BMI >35 kg/m²) and OSA (AHI >5 events/hour). We excluded subjects who did not consent or who had underlying obesity hypoventilation syndrome (OHS) without OSA or who had underlying co-morbidities that worsen apnoea symptoms such as congestive cardiac failure, active malignancy, narcolepsy, active alcohol or drug abuse, treatment-refractory dementia, psychotic illness and active use of drugs that disturb the sleep architecture (i.e. hypnotics or stimulants of central nervous system). All subjects provided written informed consent.

Subjects were evaluated prior to bariatric surgery and were reassessed 12±2 weeks after bariatric surgery. Demographic data (age, sex and ethnicity), anthropometric data (height, weight and BMI), subjective data (ESS) and objective data (partial sleep study, full lung function tests and 6MWT) were collected.

We performed an in-lab sleep study type 3 polysomnography (PSG) using the SOMNOtouch™ (Somnotec, Selangor, Malaysia). Attachment of the device was done by trained respiratory technicians. The full lung function test was performed using the Vmax™ Autobox System (DanMedik, Selangor, Malaysia) and complied with the American Thoracic Society and European Respiratory Society guidelines. All subjects were monitored by a trained respiratory technician throughout the procedure. The 6MWT was conducted at the PPUKM respiratory laboratory. Subjects were instructed to walk as far as possible in six minutes back and forth over a six-metre walking course due to infrastructure limitation in our respiratory laboratory. The ESS is a self-administered validated questionnaire comprising an eight-item scale. Subjects were asked to rate the likelihood of dozing in eight different daily lifestyle activities from 0 (would never dose) to 3 (high chance of dozing). Higher cumulative scores indicate greater excessive daytime somnolence.

Taking the power of the study to be 80% with an alpha of 0.05, a standard deviation of AHI 22.8 events/hour from a published study by Lettieri et al.19 and interpreting using the power table, the resulted sample size was estimated to be 15 patients, with an anticipated withdrawal rate of 10%. The total number of patients needed was therefore 17 patients.

All data collected are shown as mean±standard deviation when applicable. All tests are two-tailed, and a p-value of <0.05 was presumed to represent statistical significance. A paired t-test was used to compare pre- and postoperative results. Pearson correlation coefficients were used to analyse variables of anthropometric measures, lung functions tests (FEV1, FVC, ERV, RV, DLCO Adj, DLVA Adj and TLC) and 6MWT results. All analysis was performed using IBM SPSS Statistics for Windows v 25.0 (IBM Corp., Armonk, NY). As this was an exploratory study, a control for multiple comparisons was not considered.

Methods

This was a prospective longitudinal study conducted between May and September 2019 following approval from the Research Ethics Committee Hospital Canselor Tuanku Muhriz Pusat Perubatan Universiti Kebangsaan Malaysia (PPUKM; research code FF-2019-151) and the Ministry of Health Malaysia (NMIRR Research ID 50566). A flow diagram of the study design is shown in Figure 1.
surgery, while another six subjects did not turn up for follow-up. Among the reasons for not attending post-bariatric reassessment was migration to different cities and logistical issues.

The demographic and anthropometric characteristics of the subjects are shown in Table 1. The ratio of males to females was 1:2. The mean age was 36.2±5.7 years. Malays comprised 83% of the subjects, while the rest were Indians. The main ethnic group in Malaysia was not represented in this study. The baseline mean weight was 124.1±21.8 kg, and the mean BMI was 45.5±5.8 kg/m². All subjects underwent

![Study flow chart.](image)

**Figure 1.** Study flow chart.

**Table 1.** Demographic and anthropometric data of subjects.

| Data                      | Pre bariatric surgery | Post bariatric surgery (3 months) | p-Value |
|---------------------------|-----------------------|----------------------------------|---------|
| Age (years)               | 36.17±5.75            | 36.17±5.75                       |         |
| Sex                       |                       |                                  |         |
| Male                      | 4                     | 4                                |         |
| Female                    | 8                     | 8                                |         |
| Ethnicity                 |                       |                                  |         |
| Malay                     | 10                    | 10                               |         |
| Indian                    | 2                     | 2                                |         |
| Height (m)                | 1.64±0.08             | 1.64±0.08                        |         |
| Weight (kg)               | 124.1±21.8            | 107.4±20.0                       | <0.05   |
| BMI (kg/m²)               | 45.5±5.8              | 39.7±5.2                         | <0.05   |
| Co-morbidities            |                       |                                  |         |
| Hypertension              | 4                     |                                  |         |
| Type 2 DM                 | 3                     |                                  |         |
| Dyslipidaemia             | 3                     |                                  |         |
| GERD                      | 2                     |                                  |         |

DM: diabetes mellitus; GERD: gastroesophageal reflux disease.
There was a significant weight reduction, with a mean weight difference of 16.7 ± 5.0 kg, a mean percentage of weight loss (%WL) of 13.48 ± 3.53 and a mean BMI difference of 5.75 ± 1.33 kg/m².

Out of 12 subjects with morbid obesity and OSA, 33% had hypertension, 25% had underlying type 2 diabetes mellitus (DM) and dyslipidaemia and 16% had gastroesophageal reflux disease. Ninety-two per cent of subjects had at least one co-morbidity.

The values of pulmonary parameters, sleep parameters and the 6MWT pre and post bariatric surgery are presented in Table 2. All subjects who underwent bariatric surgery showed a marked improvement pre and post bariatric surgery. Pre bariatric surgery, 58% of subjects had severe OSA, 25% had moderate OSA and 17% had mild OSA. Post bariatric surgery, 17% had no OSA, 50% had mild OSA and 25% had moderate OSA. However, 8% had persistent severe OSA. There was a significant reduction in AHI, with a mean difference of 13.08 ± 5.71 events/hour post bariatric surgery. The correlation between improvement in AHI and reduction in weight is shown in Figure 2. Subjective measurement based on ESS score also showed an improvement, with a mean difference of 8.2 ± 3.4 post bariatric surgery (Figure 3).

**Discussion**

Obesity is a global health problem that has been linked with non-communicable diseases such as cardiovascular and metabolic diseases, immunological disorders, chronic kidney disease and sleep apnoea.20 Obesity affects an individual's physical health, cognitive function and overall quality of life. Furthermore, obesity leads to increased healthcare costs, with a mean weight difference of 16.7 ± 5.0 kg, a mean percentage of weight loss (%WL) of 13.48 ± 3.53 and a mean BMI difference of 5.75 ± 1.33 kg/m².

### Table 2. Comparison of sleep, pulmonary parameters and 6-MWT pre and post bariatric surgery.

| Data                              | Pre bariatric surgery | Post bariatric surgery (3 months) | p-Value |
|-----------------------------------|-----------------------|-----------------------------------|---------|
| AHI (events/hour)                 | 24.75±9.51            | 11.67±5.92                        | <0.05   |
| Nadir SpO₂ (%)                    | 83.6±3.8              | 85.0±3.3                          | 0.008   |
| ESS                               | 16±4                  | 7±3                               | 0.001   |
| FEV₁ (L)                          | 2.66±0.35             | 2.89±0.4                          | 0.03    |
| FVC (L)                           | 3.23±0.45             | 3.42±0.47                         | <0.05   |
| TLC (L)                           | 4.97±1.19             | 5.21±1.12                         | <0.05   |
| ERV (L)                           | 0.51±0.46             | 0.63±0.43                         | <0.05   |
| RV (L)                            | 1.46±0.91             | 1.64±0.92                         | <0.05   |
| DLCO Adj (mL/mmHg/min)            | 22.71±5.22            | 22.84±5.19                        | 0.04    |
| DLVA Adj (mL/mmHg/min/L)          | 5.61±0.90             | 3.23±1.16                         | 0.002*  |
| 6MWT (m)                          | 293±49                | 337±48                            | <0.05   |

*Wilcoxon signed rank test.

AHI: Apnoea–Hypopnoea Index; SpO₂: nadir mean oxygen saturation during sleep; ESS: Epworth Sleepiness Scale; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; TLC: total lung capacity; ERV: expiratory reserve volume; RV: residual volume; DLCO Adj: adjusted diffusing lung capacity for carbon monoxide; DLVA Adj: adjusted diffusing lung capacity corrected for alveolar volume; 6MWT: six-minute walk test.

**Figure 2.** Correlation between percentage weight loss and the difference in the Apnoea–Hypopnoea Index post bariatric surgery.

**Figure 3.** Distribution of Epworth Sleepiness Scale score.
productivity and quality of life and leads to early disability, early retirement and even premature death. Our subjects were slightly younger compared to Western countries, with a mean age of 36 ± 6 years. The incidence of obesity was higher in females and those of Malay ethnicity in our study. This is consistent with the NHMS 2015 data where females had a higher prevalence (20.6%) compared to males (15%). In that survey, the prevalence of obesity was highest in Indians (27.1%). Our study had 10 Malay, two Indians and no Chinese subjects.

Consistent with previous studies, 92% of our subjects reported at least one co-morbidity. Of the 12 subjects, four had underlying hypertension, three had type 2 DM and three had dyslipidaemia. It is hypothesised that obesity leads to increase visceral fat, which results in increase expression of angiotensin II and angiotensin I, predisposing them to hypertension. High insulin resistance with failure of insulin production increases the risk of type 2 DM in obese patients. Although we did not look for the effect of bariatric surgery on major co-morbidities, studies and meta-analyses have proven that bariatric surgery decreases the prevalence of hypertension, type 2 DM and dyslipidaemia.

Achieving a sufficient and sustainable weight reduction is the main treatment strategy against obesity. Lifestyle modification alone has good short-term results, but up to 66% of patients regain weight within one year. Pharmacotherapy in conjunction with lifestyle interventions has shown a better outcome. However, maintaining a sustained weight loss is still difficult, and many fail to achieve this. Bariatric surgery as an adjunctive treatment has demonstrated a sustainable and greater degree of weight loss compared to conventional therapy alone. This is especially true in SG and RYGB. SG was the preferred method at our centre, as most of our subjects had a BMI > 35 kg/m² with at least one co-morbidity. SG has been shown to be an easier and safer technique which can be performed with different degrees of intestinal bypass. SG has also been shown to improve risk according to the American Association of Anesthesiologists, and when combined with the laparoscopic approach, it can further reduce major complications post operation and is generally better tolerated. Twelve of our subjects complained of bloatedness, regurgitation and nausea post laparoscopic SG. The number of subjects with these symptoms decreased, with only four subjects with persistent symptoms after 12 weeks. While symptoms of regurgitation may have an effect on FEV₁, this was not the case in our study.

Our study showed a mean weight loss of 16.7 ± 5 kg within three months. Reports have shown that the peak average percentage of weight loss is seen at nine months and is sustained for more than 18 months. The steepest inclination degree of weight loss is seen in the first six months post bariatric surgery and plateaus after 12 months.

Weight loss has been shown to have a clinically relevant effect on OSA at one year, and this effect has been seen even at four years of follow-up. A prospective multi-centre
study involving 132 patients showed that OSA was cured in 45% of cases and cured or improved in 78% of cases after bariatric surgery. The improvement in OSA appears to be greater in patients with more severe disease. From our results, the AHI reduced from a mean AHI of 24.75 events/hour to 16.7 events/hour post bariatric surgery. The improvement in AHI correlated with weight loss, as the more weight loss achieved by the greater the reduction in AHI. In comparison to other studies, our study was conducted using a type 3 unattended PSG. As such, we were unable to identify subjects who may have overlap OSA with OHS. The prevalence of OHS in the obese population is estimated to be between 8% and 20%, and patients are typically morbidly obese with severe OSA and hypersomnolence. This may explain why our subjects only showed an improvement in mean nadir SpO2 of only 2% after bariatric surgery.

Continuous positive airway pressure (CPAP) therapy remains the gold standard treatment for OSA. It is recommended that CPAP therapy be initiated early prior to bariatric surgery and continued until reassessment of OSA is done after surgery. In our study, only one subject agreed and was commenced on CPAP therapy and continued on it after the surgery, while the rest were not keen due to logistical and cost issues. In our study, we demonstrated a significant improvement in AHI and symptoms based on the ESS pre and post bariatric surgery. These findings are similar to previous studies, although these studies were conducted over a longer duration, and the mean AHI was higher at 54.69 events/hour. In our study, there were subjects with baseline severe OSA that had persistent AHI >5 events/hour; despite an improvement in ESS score after achieving sufficient weight loss post bariatric surgery. This group of patients, termed as non-sleepy OSA, is challenging for clinicians to treat. A review of the non-sleepy OSA subgroup of patients by Montserrat et al. showed conflicting results, and more evidence is needed before initiating CPAP therapy. Most of these patients do not adhere to long-term CPAP therapy, as they deny symptoms of excessive daytime somnolence, with 70% of patients having elevated levels of AHI post bariatric surgery, with a mean ESS score of 10.8 ± 4.10, who discontinue CPAP therapy on their own.

Obesity is associated with a decrease in lung function. In a study involving 113 patients, symptoms of OSA as well as pulmonary function measured with spirometry were found to improve significantly five years after bariatric surgery. Consistent with previous reports, our study also demonstrated a marked improvement in ERV post bariatric surgery, with increments in TLC and RV. Obesity was proven to lead to a decrease in dyspnoea and respiratory drive, and in turn an increase in the inspiratory reserve volume. It is also postulated that reduction in ERV leads to an increase in atelectasis. Achieving adequate weight loss reverses the process and thus improves the ERV. Our results are best explained by an improvement in diaphragm mobility due to a reduction in extra-pulmonary restriction and, as a result of a reduction in extra-pulmonary restriction, the available unit area of lung parenchyma for respiration improved. This was demonstrated in our study based on the marked improvement in DLVA Adj, while the DLCO Adj was preserved. To the best of our knowledge, this is the first study to use DLVA Adj to consolidate the hypothesis of the effect of obesity on respiratory mechanics.

Walking is a fundamental activity of life and reflects the capacity of an individual to undertake daily activities. In our study, we used the 6MWT as a surrogate quantifier for physical activity. It is neither specific nor sensitive, but the 6MWT has three distinct advantages. It is simple, affordable and can be done by obese subjects who are unable to tolerate maximum exercise capacity such as cycling or using a treadmill. In our study, we found an increment ranging from 40 to 80 m post bariatric surgery. The distance achieved appeared to be better with a higher degree of weight loss. In comparison with previous studies, where an average increment of 150 m was seen in subjects post bariatric surgery, we believe that our results were less because our subjects failed to achieve their maximum possible weight loss. Previous studies took longer (6 or 12 months) post bariatric surgery before repeating the test.

OSA, like obesity, is a chronic progressive disease and is associated with a relapse in weight regain as reported in a meta-analysis which showed that at 20 years, only 48.9% of subjects had excess weight loss. From our study, the role of bariatric surgery as a treatment strategy for weight reduction in obese patients should be further integrated and utilised in Malaysia. Bariatric surgery should not be considered as a ‘last option treatment’; nor should it be considered as a ‘cure all’. Laparoscopic SG is a safe and well-tolerated method of bariatric surgery. It is also associated with fast recovery and provides good outcome.

Our study showed the positive impact of bariatric surgery in reducing the AHI due to adequate and effective weight loss as early as three months post surgery. The reduction in abdominal girth and improvement in lung function reduces airway obstruction. For OSA patients who have difficulty tolerating CPAP or who do not adhere to CPAP therapy, bariatric surgery is a possible treatment option. For severe OSA patients, early initiation of CPAP at least four to six weeks prior to surgery and post surgery until further assessment of OSA by a respiratory physician before discontinuing CPAP therapy remains beneficial. Based on our results, a reassessment of sleep apnoea can be done as early as three months and is comparable to studies in which their reassessment was done at 6, 9 or 12 months.

Our results support the findings of a meta-analysis that showed that bariatric surgery compared to non-surgical treatment of obesity has a greater effect on weight loss. In the same study, waist circumference appeared to decrease more after bariatric surgery than after non-surgical treatment. We did not use accelerometers, pedometers or the internal physical activity questionnaire as tools to quantify physical activity levels in our study. We chose the 6MWT because it is a safe, cheap and simple procedure and has been used as a clinical indicator for improvement of physical activity post bariatric surgery. The 6MWT provides a quantitative measurement to assess the physical activity of each individual, while a quality-of-life questionnaire provides the qualitative index. Using both clinical instruments, the treating clinicians can gauge and prescribe a better physical rehabilitation programme post bariatric surgery in order to maximise the achievable weight loss post bariatric surgery.

This study has some limitations. The sharp incline in degree of weight loss during the first three months is likely to be
influenced by short-term behavioural changes (i.e. healthy diet and increased physical activity). However, the short follow-up may underestimate the improvement in pulmonary parameters and sleep apnoea post bariatric surgery, as the patients might not yet have reached the maximum achievable and sustainable weight loss. Second, we did not address the dietary habits and the physical activity of our subjects. This may further underestimate the effects of bariatric surgery. Furthermore, in this study, type 3 PSG was used instead of type 1 PSG. A type 1 attended full PSG with an arterial blood gas measurement would provide more data and enable subjects with overlap OSA and OHS to be analysed. Another limitation is the small sample size of 12 subjects.

Conclusion

Obesity is a chronic progressive disease associated with metabolic conditions. In our study, laparoscopic bariatric surgery showed an improvement in AHI and pulmonary function parameters (e.g. lung volume, gas transfer and FEV1). This study describes the benefits of bariatric surgery in OSA patients as early as three months post surgery.

Acknowledgements

The authors would like to thank all participants for their involvement and cooperation during the course of this study. We are also grateful to Universiti Kebangsaan Malaysia for providing us fundamental grant with research code FF-2019-151.

Authors’ contributions

All authors were involved in literature review, study proposal submission to the Institutional Review Board, data collection, data analysis and paper write-up.

Availability of data and materials

The data sheets generated and analysed during the study are available from Dr Ahmad Adib Bin Mohd Nasir.

Ethical approval

Ethical approval to report these cases was obtained from the Research Ethics Committee of the Universiti Kebangsaan Malaysia, Kuala Lumpur, 2015.

Informed consent

Written informed consent was obtained from all participants before the study.

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This research received grant from the Universiti Kebangsaan Malaysia (FF-2019-151).

ORCID iD

Faisal Abdul Hamid https://orcid.org/0000-0002-7526-361X

References

1. World Health Organization. Obesity: preventing and managing the global epidemic : report of a WHO consultation. WHO Technical Report Series 894, Geneva: World Health Organization, 2000.
2. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet 2014; 384: 766–778.
3. Chan YY, Lim KK, Lim KH, et al. Physical activity and overweight/obesity among Malaysian adults: findings from the 2015 National Health and Morbidity Survey (NHMS). BMC Public Health 2017; 17: 733.
4. Mohamud WNW, Imran MK, Sharifuddin A, et al. Prevalence of overweight and obesity among adult Malaysians: an update. Asia Pac J Clin Nutr 2011; 20: 35–41.
5. Institute for Public Health. National Health and Morbidity Survey 2015 (NHMS 2015). Vol. II: non-communicable diseases, risk factors and other health problems. Institute for Public Health, National Institutes of Health, Ministry of Health, Malaysia, Kuala Lumpur, 2015.
6. Jones RL and Nzekwu MM. The effects of body mass index on lung volumes. Chest 2006; 130: 827–833.
7. Mafort TT, Rufino R, Costa CH, et al. Obesity: systemic and pulmonary complications, biochemical abnormalities, and impairment of lung function. Multidiscip Respir Med 2016; 11: 28.
8. Boissiere L, Bertheau A, Bertin E, et al. Improvement of dyspnea after bariatric surgery is associated with increased expiratory reserve volume: a prospective follow-up study of 45 patients. PLoS One 2017; 12: e0185058.
9. Koenig SM. Pulmonary complications of obesity. Am J Med 2001; 121: 249–279.
10. Young SS, Scharinger S, Austin T, et al. The effects of body fat on pulmonary function and gas exchange in morbidly obese monkeys. Am J Physiol 2003; 16: 313–319.
11. Greenburg DL, Lettieri CJ and Eliasson AH. Effects of surgical procedure? Obes Surg 2009; 19: 535–542.
12. Mortimore IL, Marshall IL, Wraith PK, et al. Neck and total body fat deposition in nonobese and obese patients with sleep apnea compared with that in control subjects. Am J Respir Crit Care Med 1998; 157: 280–283.
13. De Sousa AG, Cerqueto C, Mancini MC, et al. Obesity and obstructive sleep apnea–hypopnea syndrome. Obes Rev 2008; 9: 340–354.
14. De Souza SAF, Faintuch J, Valezi AC, et al. Gait cinematic analysis in morbidly obese patients. Obes Surg 2005; 15: 1238–1242.
15. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. Am J Respir Crit Care Med 2002; 166: 111–117.
16. Buchwald H, Avidor Y, Braunwald E, et al. Bariatric surgery: a systematic review and meta-analysis. JAMA 2004; 293: 1724–1728.
17. National Institute for Health and Care Excellence. Obesity prevention, https://www.nice.org.uk/guidance/cg43 (2006, accessed 5 March, 2019).
18. Benages D, Masi-Lorenzo A, Goday A, et al. Laparoscopic sleeve gastrectomy: more than a restrictive bariatric surgery? World J Gastroenterol 2015; 21: 11804–11814.
19. Lettieri CJ, Eliasson AH and Greenburg DL. Persistence of obstructive sleep apnea after surgical weight loss. J Clin Sleep Med 2008; 4: 333–338.
20. Guh DP, Zhang W, Bansback N, et al. The incidence of comorbidities related to obesity and overweight: a systematic review and meta-analysis. BMC Public Health 2009; 9: 88.
21. European Association for the Study of Obesity. Being a car commuter with obesity linked to a 32% increased early death risk. https://www.sciencedaily.com/releases/2019/04/190427201946.htm (2019, accessed 1 October, 2019).
22. Fierabracci P, Tamberi A and Santini F. Obesity-related comorbidities. In: Lucchese M and Scopinaro N (eds) Minimally invasive bariatric and metabolic surgery. Cham: Springer, 2015, pp.25–34.
23. Cremieux PY, Ledoux S, Clerici C, et al. The impact of bariatric surgery on comorbidities and medication use among obese patients. Obes Surg 2010; 20: 861–870.
24. Narbro KÅG, Jonsson E, Näslund I, et al. Pharmaceutical costs in obese individuals: comparison with a randomly selected population sample and long-term changes after conventional and surgical treatment: the SOS intervention study. Arch Intern Med 2002; 162: 2061–2069.
25. McTigue KM, Harris R, Hemphill B, et al. Screening and interventions for obesity in adults: summary of the evidence for the U.S. Preventive Services Task Force. Ann Intern Med 2003; 139: 933–949.
26. Reoch J, Mottillo S, Shimony A, et al. Safety of laparoscopic vs open bariatric surgery: a systematic review and meta-analysis. Arch Surg 2011; 146: 1314–1322.
27. Manning S, Pucci A, Carter NC, et al. Early postoperative weight loss predicts maximal weight loss after sleeve gastrectomy and Roux-en-Y gastric bypass. Surg Endosc 2015; 29: 1484–1491.
28. Kuna ST, Reboussin DM, Borradaile KE, et al. Long-term effect of weight loss on obstructive sleep apnea severity in obese patients with type 2 diabetes. Sleep 2013; 36: 641–649A.
29. Foster GD, Borradaile KE, Sanders MH, et al. A randomized study on the effect of weight loss on obstructive sleep apnea among obese patients with type 2 diabetes. The Sleep AHEAD Study. Arch Intern Med 2009; 169: 1619–1626.
30. Peromaa-Haavisto P, Tuomilehto H, Kossi J, et al. Obstructive sleep apnea: the effect of bariatric surgery after 12 months. A prospective multicenter trial. Sleep Med 2017; 35: 85–90.
31. Johansson K, Neovius M, Lagerros YT, et al. Effect of a very low energy diet on moderate and severe obstructive sleep apnoea in obese men: a randomised controlled trial. BMJ 2009; 339: b4609.
32. Masa JF, Pepin JL, Borel JC, et al. Obesity hypoventilation syndrome. Eur Respir Rev 2019; 28: 180097.
33. ASMBS Clinical Issues Committee. Peri-operative management of obstructive sleep apnea. Surg Obes Relat Dis 2012; 8: e27–e32.
34. Montserrat JM, Garcia-Rio F and Barbe F. Diagnostic and therapeutic approach to nonsleepy apnea. Am J Respir Crit Care Med 2007; 176: 6–9.
35. Hewitt S, Humerfelt S, Søvik TT, et al. Long-term improvements in pulmonary function 5 years after bariatric surgery. Obes Surg 2014; 24: 705–711.
36. Maniscalco M, Zedda A, Giardiello C, et al. Effect of bariatric surgery on the six-minute walk test in severe uncomplicated obesity. Obes Surg 2006; 16: 836–841.
37. Hansen N, Hartin E, Bates C, et al. Preoperative change in 6-minute walk distance correlates with early weight loss after sleeve gastrectomy. JLS 2014; 18: e2014.00383.
38. O’Brien PE, Hindle A, Brennan L, et al. Long-term outcomes after bariatric surgery: a systematic review and meta-analysis of weight loss at 10 or more years for all bariatric procedures and a single-centre review of 20-year outcomes after adjustable gastric banding. Obes Surg 2019; 29: 3–14.
39. Gloy VL, Briel M, Bhatt DL, et al. Bariatric surgery versus non-surgical treatment for obesity: a systematic review and meta-analysis of randomised controlled trials. BMJ 2013; 347: f5934.