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ORIGINAL CONTRIBUTIONS

Self-Reported Smoking Compared to Serum Cotinine in Bariatric Surgery Patients: Smoking Is Underreported Before the Operation

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Abstract

Background Smoking has been associated with postoperative complications and mortality in bariatric surgery. The evidence for smoking is based on self-report and medical charts, which can lead to misclassification and miscalculation of the associations. Determination of cotinine can objectively define nicotine exposure. We determined the accuracy of self-reported smoking compared to cotinine measurement in three phases of the bariatric surgery trajectory.

Methods Patients in the phase of screening (screening), on the day of surgery (surgery), and more than 18 months after surgery (follow-up) were consecutively selected. Self-reported smoking was registered and serum cotinine was measured. We evaluated the accuracy of self-reported smoking compared to cotinine, and the level of agreement between self-report and cotinine for each phase.

Results In total, 715 patients were included. In the screening, surgery, and follow-up group, 25.6%, 18.0%, and 15.5%, respectively, was smoking based on cotinine. The sensitivity of self-reported smoking was 72.5%, 31.0%, and 93.5% in the screening, surgery, and follow-up group, respectively ($p < 0.001$). The specificity of self-report was > 95% in all groups ($p < 0.02$). The level of agreement between self-report and cotinine was 0.778, 0.414, and 0.855 for the screening, surgery, and follow-up group, respectively.

Conclusions Underreporting of smoking occurs before bariatric surgery, mainly on the day of surgery. Future studies on effects of smoking and smoking cessation in bariatric surgery should include methods taking into account the issue of underreporting.

Keywords Bariatric surgery · Smoking · Cotinine · Self-report · Underreporting · Complication

Introduction

Bariatric surgery is the most effective weight loss therapy for treating morbid obesity. Besides weight loss, it contributes to improvements in comorbidity and reduces mortality [1, 2]. Smoking has been associated with postoperative complications and mortality in bariatric surgery [3–5]. Short-term effects of smoking cessation have shown to significantly

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improve pulmonary function and immune function [6, 7], and smoking cessation is thereby likely to decrease postoperative complications [8–10]. Therefore, patients are strictly urged to quit smoking before undergoing bariatric surgery.

However, the evidence on the associations between smoking and postoperative complications or influence on weight loss is based on self-report and medical charts [3–5, 11–17]. It may lead to misclassification if patients conceal their smoking habits. This is a common problem in studies [18, 19]. Studies on the relationship between self-reported smoking status and objectively measured nicotine exposure have shown that misclassification is greater in clinical situations where quitting expectations on part of the health care team influence self-report [18–21]. Cotinine is the biomarker of choice to objectively define nicotine exposure. It can be measured in serum, urine, and saliva [18, 19, 22].

Therefore, we evaluated the accuracy of self-reported smoking in three groups of patients based on cotinine measurement: patients screened for bariatric surgery, patients on the day of bariatric surgery, and patients more than 18 months after surgery. Additionally, we evaluated whether smoking based on cotinine measurement and self-reported were associated with the occurrence of postoperative complications. We hypothesized that self-reported smoking status may be less accurate in the phase before surgery when patients may be afraid that smoking will contribute to rejection for bariatric surgery compared to smoking status during follow-up after the operation.

Materials and Methods

Setting and Study Population

Between the 4th of January 2017 and the 24th of April 2017, all bariatric surgery patients of a high-volume bariatric center of excellence visiting the laboratory were consecutively screened. As a part of the bariatric care protocol, blood samples are taken from patients at specific time points before and after surgery. Patients in this cohort were urged to quit smoking at least 2 weeks prior to the surgery. They were counseled and were offered support by the general practitioner or smoking cessation department. Three groups were selected: patients in the phase of screening for bariatric surgery (screening), on the day of bariatric surgery (surgery), and patients more than 18 months after bariatric surgery (follow-up). We asked patients whether they were willing to answer questions on smoking behavior and allow us to extract serum from the blood already drawn for clinical management. Exclusion criteria included age under 18 years old, bariatric surgery less than 18 months ago, or missing blood sample.

The local Medical Ethics Committee at former MC Slotervaart approved the study protocol. All patients provided written informed consent before enrolment.

Data Collection

After enrolment all patients were asked to report their current and past nicotine exposure. Afterwards, blood was drawn. Variables that were extracted from medical records included sex, age at time of cotinine measurement, preoperative weight and body mass index, type of bariatric surgery, primary or revisional bariatric surgery, history of abdominal surgery, hypertension, and diabetes mellitus. In the follow-up group, we also collected information on time after surgery, percentage total weight loss, proton pump inhibitor use, and postoperative presence of hypertension and diabetes.

Self-Reported Smoking and Smoking According to Cotinine

Current smoking was defined as smoking at least once during the past 2 days, because of the half-life of cotinine [19, 22–25].

Self-Report

Patients filled out a written questionnaire questioning whether they had smoked (ever), had used nicotine replacing products, or were exposed to secondhand smoking during the last 48 h. Additionally, (former) smokers answered when they had smoked the last one.

Cotinine

Serum was extracted and samples were stored at − 20 °C until analysis. Samples were obtained prospectively and analysis was performed collectively. The standard samples (calibrators and controls) were handled similarly.

Cotinine was extracted with solid-phase extraction (SPE), and quantitation was performed by reversed-phase high-performance liquid chromatography (HPLC) with UV detection [26–31]. Cotinine was detected with UV absorbance wavelength set at 259 nm and identified by retention time index (0.38). Internal standard used was 2-phenylimidazole. The quantitation limit of cotinine was 10 ng/ml. The intra-assay and inter-assay coefficients of variation were 8% and 13%, respectively. Cotinine test was defined as positive when cotinine concentration was ≥ 10 ng/ml.

The HPLC-system consisted of Varian ternair pump, Varian ProStar auto sampler, and Varian Prostar Diode Array Detector. The columns used were Bond Elut C2-solid phase extraction columns (3 ml/200 mg) and HPLC analytical column: Inertsil C8; 3.0 × 150 mm, 5 μ. Software used for

controlling the HPLC-system and data processing was Galaxie chromatography software.

The technician and the blood samplers were non-smokers. Naturally, there was an interdiction to smoke in the analytical laboratory. The results of the cotinine test were never visible for the attending doctors.

Complications

Complications during the first 30 days after surgery were retrieved from the medical records. We used the Clavien Dindo classification for severity of the complications [32].

Statistical Analysis

Primary, we calculated the sensitivity and specificity of self-reported smoking, also for each group separately (screening, surgery, follow-up). Chi^2 test was used to compare sensitivity between the three groups. The degree of agreement between self-report and cotinine measurement was expressed using Cohen's kappa coefficient, also for each group.

Secondary, patients were grouped in four classification groups combining the self-report and the cotinine test (patients who reported smoking accurately, patients who concealed smoking, patients who correctly reported non-smoking, or those who reported smoking inaccurately). Then, baseline characteristics were compared using chi^2 test, one-way ANOVA, or Kruskal Wallis test, in case of categorical variables, normal distributed variables, or non-normal distributed data respectively. Finally, in case of p value < 0.200, group differences were tested separately using chi^2 test, unpaired T test, or Mann-Whitney U test if applicable. We calculated cotinine concentrations per classification group and described exposure to secondhand smoking and nicotine replacement products.

Finally, the associations between smoking, self-reported or defined by cotinine measurement, and complications during the first 30 days after bariatric surgery were explored using univariable logistic regression. We adjusted for possible confounding, by adding variables with p value < 0.400 after univariable logistic regression to the model.

Data analysis was performed using IBM SPSS Statistics software package for Windows version 22 (Chicago, Illinois).

Results

During the screening period, a total of 742 patients was eligible for the study. Twenty-seven patients were excluded; 13 in the screening, nine in the surgery, and five patients in the follow-up group. Patient characteristics are described in Table 1. Median time after surgery of follow-up group was 2.9 years (interquartile range 2.0–3.8). Mean total weight loss was 30.5% (standard deviation 9.0). Postoperative, 43 (21.5%) patients had hypertension, 11 (5.5%) diabetes mellitus 2, and 62 (31.0%) patients used proton pump inhibitors.

Smoking: Self-Reported and Based on Cotinine Measurement

In Table 2, self-reported smoking, positive cotinine (≥ 10 ng/ml), cotinine concentration, sensitivity, specificity and Cohen's kappa coefficient per group are summarized. Smoking based on cotinine measurement was 25.6%, 18.4%, and 15.5% in the screening, surgery, and follow-up group, respectively. A history of smoking was reported by 41.2%, 49.4%, and 39.0% of the patients, in the screening, surgery, and follow-up group, respectively. The sensitivity of self-reported smoking was 72.5%, 31.0%, and 93.5% in the screening, surgery, and follow-up group, respectively ($p < 0.001$). The specificity of self-report was 99.6%, 99.3%, and 96.4% in the screening, surgery, and follow-up group, respectively ($p < 0.02$). The kappa between self-report and cotinine was 0.784 for the screening group, 0.414 for the surgery group, and 0.855 for the follow-up group.

Fifty-three of 199 patients in the screening group were not operated for several reasons. In 22 (41.5%) of them, cotinine was detected, and 16 (30.2%) reported smoking. Once, an unsuccessful cessation of smoking was mentioned as reason for postponement of the operation.

Accuracy of Self-Report and Exposure to Other Types of Nicotine

We found no clinically relevant differences in baseline characteristics between patients who reported smoking accurately, patients who concealed smoking, patients who reported correctly to be non- smoking, or those who inaccurately reported to be smoking (data not shown).

In Table 3, cotinine values and characteristics of secondhand smoking exposure are shown, in all patients and grouped on accuracy of self-report. Overall, seven patients (< 1%) had used e-cigarettes, and no other type of nicotine replacement product was reported. Two of the seven patients reported also to be a current smoker (one in screening and one in follow-up group). Five patients (all in the surgery group) reported to have already stopped with cigarette smoking; the shortest cessation period was 2.3 months, the longest 4 years. All cotinine levels were above 180 ng/ml (mean 284.8 ng/ml (SD 67.4)).

30-Day Complications

For the relationship between self-reported smoking, cotinine, and complications within 30 days after surgery, we analyzed the screening group and the surgery group (Total $n = 461$).

Table 1 Demographic and clinical characteristics before surgery, per group (screening, surgery, follow-up)

	Screening $N = 199$	Surgery $N = 316$	Follow-up $N = 200$
Female gender, *N* (%)	157 (78.9)	268 (84.8)	171 (85.5)
Age (years), mean (SD)	44.6 (11.4)	46.3 (10.3)	48.2 (11.2)
Weight (kg), mean (SD)	124.2 (20.7)	122.0 (18.5)	124.9 (17.8)
Body mass index (kg/m^2), median (IQR)	42.0 (39.7–45.8)	41.8 (39.6–44.6)	42.3 (39.8–46.3)
Hypertension, *N* (%)	78 (39.2)	133 (42.1)	72 (36.0)
Diabetes mellitus 2, *N* (%)	43 (21.6)	81 (25.6)	40 (20.0)
Previous abdominal surgery, *N* (%)[c]	102 (51.3)	153 (48.4)	118 (59.0)
Interval between cotinine and surgery (weeks) median (IQR)	19.0 (16.0–24.0)*		
Primary bariatric surgery, *N* (%)	139 (95.2)[a]	288 (91.1)[b]	174 (87.0)

N number, *IQR* interquartile range, *SD* standard deviation

[a] Operated patients only. 53 patients were not operated.

[b] One patient was not operated

[c] Including bariatric surgery

Overall, 73 (15.8%) of these patients had a surgical complication (bleedings ($n = 22$), nausea or dysphagia ($n = 11$), abdominal pain ($n = 7$), infection ($n = 7$), leakage of anastomosis ($n = 6$), stenosis ($n = 5$), allergic reaction ($n = 3$), other complications ($n = 11$), and one patient died. Forty-seven complications (10.2%) were classified as Clavien Dindo I, 15 (3.3%) as Clavien Dindo II; 10 complications (2.2%) were categorized as Clavien Dindo III, and one complication (0.2%) as Clavien Dindo V.

In the screening group, cotinine was detected in eight (33%) of the patients with a complication and in 21 (17%) without complication. Smoking was reported by seven patients (29%) with a complication and by 14 (12%) without a complication. The adjusted odds ratios for having a postoperative complication were 3.8 (1.3–11.3) for positive cotinine and 5.1 (1.6–16.4) for self-reported smoking. We adjusted for presence of type 2 diabetes, preoperative BMI, time before surgery, and primary bariatric surgery (Table 4).

In the surgery group, cotinine was detected in eight patients (15%) with a complication and in 49 (19%) without a complication. Smoking was reported by three patients (6%) with a complication and by 16 (6%) without a complication. In this group, the adjusted odds ratios for having a postoperative complication were 0.9 (0.4–2.2) for positive cotinine and 1.1 (0.3–3.9) for self-reported smoking. We adjusted for gender, preoperative BMI, age, and presence of hypertension (Table 5).

Discussion

This is the first study in bariatric surgery examining the accuracy of self-reported smoking status. When smoking was based on cotinine concentration, 15.5–25.6% of all patients was currently smoking on the different time points before and after surgery. As hypothesized, underreporting of smoking is

Table 2 Self-reported smoking versus positive cotinine; sensitivity, specificity, and Cohen's kappa coefficient

	All patients $N = 715$	Screening $N = 199$	Surgery $N = 316$	Follow-up $N = 200$
Self-reported smoking, *N* (%)	92 (12.9)	38 (19.1)	19 (6.0)	35 (17.5)
Self-reported history of smoking, *N* (%)	316 (44.2)	82 (41.2)	156 (49.4)	78 (39.0)
Cotinine detected, *N* (%)	140 (19.6)	51 (25.6)	58 (18.4)	31 (15.5)
Cotinine concentration (ng/ml), median (IQR)ǂ[a]	115.0 (50.3–213.5)	101.0 (26.0–159.0)ǂ	117.0 (28.0–236.8)ǂ	180 (81.0–249.0)ǂ
Sensitivity of self-report (%)	60.0	72.5#	31.0#	93.5#
Specificity of self-report (%)	98.6	99.6*	99.3*	96.4*
Cohen's kappa coefficient	0.673	0.784	0.414	0.855

[a] Only values of positive cotinine (concentration ≥ 10 ng/ml) are described

[#] Significant difference between groups: $p < 0.001$; *Significant differences between groups: $p < 0.02$; [ǂ] Significant differences between groups: $p < 0.01$

Table 3 Description of cotinine values and secondhand smoking exposure, in all patients and grouped on accuracy of self-report

	All patients *N* = 715	Correctly smoking *N* = 84	Concealed smoking *N* = 56	Correctly non-smoking *N* = 567	Incorrectly smoking *N* = 8
Cotinine (ng/ml), median (IQR)	115.0 (50.3–213.5)	143.0 (79.5–230.3)	71.0 (19.0–163.8)	–	–
Exposure to SHS, *N* (%)	190 (26.6)[a]	52 (61.9)	29 (51.8)	101 (17.8)	8 (100.0)
Time of SHS (hours), median (IQR)	1.0 (0.2–18.0)	3.0 (0.4–48.0)	8.0 (0.8–30.0)	0.5 (0.2–4.5)	3.5 (0.3–7.0)
Cotinine in SHS group (ng/ml), median (IQR)	145.0 (78.0–232.5)	162.5 (84.8–230.3)	105.0 (64.5–253.5)	–	–

N number, *IQR* Interquartile range, *SHS* secondhand smoking

[a] In 81 (42.6%) patients, cotinine was detected

present during the screening period before surgery (sensitivity 72.5%) and especially on the day of surgery (sensitivity 31.0%). This indicates that preoperative self-reported smoking is a poor indicator of actual smoking status compared to cotinine values. The self-reported smoking status is most reliable when patients are already operated (sensitivity 93.5%).

In most bariatric surgery studies, smoking is based on self-report and medical chart review [3, 11–17, 33–40]. Our study shows that it really matters at which moment smoking status is reported and that is likely that underreporting may influence results and conclusions of studies. We evaluated how and at which moment smoking status was evaluated in all studies since 2010 in which smoking status was an outcome or was associated with bariatric surgery outcome (Table 6) [3, 11–17, 33–59]. This evaluation showed that all studies were based on self-report or medical chart, and in only a few studies, a specific questionnaire was used. It also indicated that in many studies, the definitions of smoking or former smoking were not well described, and the percentages of lost to follow-up were high. This underlines that results of these studies are based on an imprecise method to evaluate smoking status and patient groups with many missing data which will definitely influence results.

Possible explanations for inaccurate self-report are high quitting expectations from the health care team, embarrassment for failing to quit, fear for gaining weight as a result of smoking cessation (which interferes with the preoperative weight goal), the stigma associated with smoking, and fear for rejection [18–20, 60]. However, fear for rejection could have been an extra motivation to stop (at least temporarily) and accept the offered support, which would abate the necessity of concealing. And, misclassification is a common problem in settings where there is no surgery involved [18–20, 61–64]. Our patients were informed that the self-report would be solely related to cotinine and would never be visible for their attending doctor. Hence, the problem of misclassification could be larger in normal practice, when patients report smoking to their attending doctor, without verification. Consequently, patients who disclose their smoking are not encouraged to attempt cessation, are poorly informed about possible positive effects of quitting, and receive no individual support.

Smoking is known to contribute to short-term and long-term postoperative complications [3–5, 12, 13, 15, 16, 34, 36, 46, 65]. In our study, current smoking based on cotinine and self-report at the phase of screening was associated with complications after surgery, but smoking at the day of surgery not. Studies on the timing of preoperative smoking cessation to effect short-term postoperative complications in the field of bariatric surgery are scarce. Mean time until surgery was approximately 5 months. Exact timing of the smoking cessation and the success rate in the screening group is unclear but was ineffective to improve complication rates. We suggest further research on this topic should use cotinine to assess preoperative smoking.

Cotinine detected at the day of surgery was not a predictor for complications, possibly due to occasional smoking out of

Table 4 Associations of self-reported and cotinine measured smoking with 30-day complications in the screening group

	Univariable OR (95 CI)	Adjusted OR (95 CI)[a]	Adjusted OR (95 CI)[b]	Adjusted OR (95 CI)[c]
Self-reported smoking	3.18 (1.12–9.00)	5.09 (1.58–16.42)	4.72 (1.49–14.98)	4.90 (1.56–15.43)
Positive cotinine	2.41 (0.91–6.35)	3.79 (1.27–11.29)	3.43 (1.18–10.01)	3.37 (1.16–9.77)

OR odds ratio, *CI* confidence interval

[a] Adjusted for BMI, DM2, preoperative time, and primary surgery ($p < 0.4$ at univariable analysis)

[b] Adjusted for BMI, DM2, and preoperative time ($p < 0.3$ at univariable analysis)

[c] Adjusted for DM2, preoperative time ($p < 0.2$ at univariable analysis)

Table 5 Associations of self-reported and cotinine measured smoking with 30-day complications in the surgery group

	Univariable OR (95 CI)	Adjusted OR (95 CI)[1]	Adjusted OR (95 CI)[2]	Adjusted OR (95 CI)[3]
Self-reported smoking	1.02 (0.29–3.64)	1.06 (0.28–3.92)	1.01 (0.28–3.71)	0.96 (0.26–3.51)
Positive cotinine	0.86 (0.38–1.96)	0.94 (0.41–2.20)	0.91 (0.39–2.09)	0.88 (0.38–2.02)

OR odds ratio, *CI* confidence interval

[a] Adjusted for sex, BMI, age, and hypertension ($p < 0.4$ at univariable analysis)

[b] Adjusted for sex, BMI, and hypertension ($p < 0.3$ at univariable analysis)

[c] Adjusted for sex and BMI ($p < 0.2$ at univariable analysis)

fear for the operation and due to a short period of smoking cessation on the other hand. Clearly, the level of cotinine on the day of surgery does not represent the impairment of organs by rarely occasional smoking or the improvement after short-term smoking cessation. The exact duration of cessation is unknown, because cotinine is generally only detectable during the first 48–96 h after inhalation of a cigarette [19, 22–25, 66, 67].

Noteworthy is the preoperative group that is not (yet) operated; 41.5% had positive cotinine test at screening. Reasons for forgoing, postponement, or rejections are diverse; only once an unsuccessful cessation of smoking was mentioned. Other studies have shown that a history of smoking is associated with longer wait times [68–70].

In spite of the preoperative urgent advice to quit smoking for a lifetime, 15% of all the patients after surgery appeared to be a current smoker. This emphasizes the ongoing need for routinely monitoring the smoking status, better counseling, and the necessity for more effective long-term smoking cessation strategies, also after surgery.

We used solid-phase extraction in combination with high-performance liquid chromatography (HPLC) to measure cotinine levels [19, 26–31]. The intra- and inter-assay variabilities indicate safe and valid use of HPLC in this study. To rule out possible interference in the determination of cotinine, we checked for peak purity for each positive cotinine test. We did not focus on the correlation between cotinine concentration and reported number of cigarettes, which may be relevant when investigating a dose response reaction.

It still may be difficult to correctly identify a smoker using cotinine taking into account the short half-life, the time between smoking and sample collection, variation in metabolism of nicotine (race, ethnicity, gender, medications, diet, age, genetic variation in CYP2A6 enzyme, pregnancy, liver or kidney disease), intermittent smokers, patients heavily exposed to secondhand smoking (SHS), and interference by species of the nightshades family. [19, 22, 25, 67, 71–80]

Nevertheless, our cut-off value was relatively high; patients (heavily) exposed to secondhand smoking often do not reach serum levels above 3 ng/ml, and in non-smoking subjects, cotinine concentrations are below 1 ng/ml [22, 67, 78, 81–84]. In active smokers, much higher concentrations have been found (often above 100 ng/ml) [73, 81, 83, 85]. In agreement with this, no positive cotinines were detected in the "correctly non-smoking and incorrectly smoking" group. Thus, the high levels of cotinine (in total and SHS subgroup) in the patients that concealed smoking and the fact that the SHS part of this group had not lower but higher values supports active smoking as explanation of increased cotinine instead of very heavy secondhand smoking. Due to variation in metabolism of cotinine and divergent steady-state levels before cessation, we cannot exclude that patients truly had stopped more than 48 h before, although this is unlikely the case in all patients [19, 22, 25, 67, 71–80].

Only five (< 1%) patients reported to have solely used electronic cigarettes during the last 48 h. We collected no further information about brand, generation, composition of vapor, level of nicotine, or experience of vaping. All these factors can influence actual nicotine delivery. Although, by vaporizing, patients often do not reach the blood levels that can be achieved by cigarette smoking [86–88]. Therefore, it is unlikely that cotinine levels of above 180 ng/ml can be explained by the use of e-cigarettes. No use of other types of nicotine replacement products was reported.

The effect of selection bias seems limited. In this large sample, we included all patients consecutively and only 27 (3.6%) patients were excluded. This high inclusion rate was established by the inclusion setting at the laboratory where the patients had to draw blood anyway. Potentially, all 27 exclusions could have been smoking; nonetheless, the percentage is low (3.6%) and suggests that reliable conclusions can be made.

In conclusion, smoking is underreported especially in patients at the day of bariatric surgery, but also in the trajectory months before surgery. Self-reported smoking is most reliable when patients are already operated. Cotinine-based and self-reported smoking was associated with the occurrence of post-operative complications at the phase of screening, but smoking at the day of screening was not. In most previous studies on smoking and bariatric surgery, outcome smoking was assessed by different types of self-report and often without precise definition and timing of smoking status. Future studies on risks of smoking should include cotinine measurement or other methods to address the issue of underreporting.

Table 6 Evaluation of definitions of smoking in all studies since 2010 in which smoking was an outcome or was associated with a bariatric outcome

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
Birkmeyer, 2010 [54]	Retrospective 15,275 35.2% LAGB, 5.6% LSG, 59.2% RYGB 1 month	Current or past smoking	Preop: medical record	30-day complications	Preop smoking prevalence 39% LAGB 36% LSG 41% RYGB 40%	No univariable analysis for smoking and complications Revisional surgery was excluded Data from MBSC dataset
Odom, 2010 [55]	Retrospective 203 RYGB 28.1 months (SD 18.9)	Not available	Preop: medical record	Predictors for postoperative weight gain (> 15% from nadir weight)	Preop smoking prevalence 4.4% Preop smoking was not a predictor for weight gain after RYGB	18% RespR (survey not concerned smoking) Unclear whether it concerned open and/or laparoscopic surgery and whether revisional surgery was included
Finks, 2011 [43]	Retrospective 25,469 54% LGBP, 4.3% OGBP, 31.5% LAGB, 8.9% SG, 1.3% DS 1 month	Any smoking history	Preop: medical record	30-day mortality and complication rate	Preop smoking prevalence 39% LGBP 40.9% OGBP 39.5% LAGB 36% SG 37.0% DS 43.4% Smoking was associated with serious complications in overall population OR 1.2 (1.02–1.40)	Revisional surgery was excluded Previous venous thromboembolism, mobility limitations, coronary artery disease, age over 50 years, pulmonary disease, male gender, and smoking history were associated with serious complications Data from MBSC dataset, overlapping cohort Birkmeyer [54]
Turner, 2011 [44]	Retrospective 32,426 LGBP 1 month	Smoking within 1 year before surgery	Preop: medical record	30-day morbidity and mortality risk	Preop smoking prevalence: 12.3% Smoking was not a 'strong contributor' to predicted probability of 30-day morbidity and mortality	Unclear whether revisional surgery was included Nomogram was not externally validated (AUC 0.629 (0.614–0.645)) Data from ACS NSQIP dataset
Adams, 2012 [36]	Retrospective 36 LAGB, 25 (L + O)RYGB Veterans 2 years	Never user, former user (quit at least 1 year prior to surgery), or recent user (quit within the year before surgery)	Medical record; Preoperative (~2 months before), 6, 12, and 24 months after surgery	Prevalence smoking and substance use disorder; Association EWL	Preop smoking prevalence: Recent 15.5% (all quit within 5 months prior to surgery) Former 37.9% Never 46.6% Postop prevalence smoking 15.5% (all recent quitters resumed) Former smokers 37.9% Never 46.6% EWL was related to smoking status at 6 and 12 months after surgery, but not anymore after 24 months. Recent smokers lost more weight than both never and former smokers. History of substance use disorder was not related to EWL	The authors state that there was a marginally significant relationship between history of substance use disorder and weight loss at 12 months and 24 months after surgery, despite p values of 0.08 and 0.09 respectively Veterans are older, more likely to be male, and have high rates of tobacco and substance use disorders. Unclear whether revisional surgery was included
Gupta, 2012 [45]	Retrospective 11,023 55.2% LRYGB, 11.1% ORYGB, 30.3% LAGB, 2.5% other GBP, 0.4% VBG, 0.5% BPD 1 month	Smoking within 1 year before surgery	Preop: medical record	30-day postop comorbidity risk	Preop smoking prevalence: 12.5% LRYGB 12.4%; ORYGB 14.7%; LAGB 12.3%; BPD 11.9%; VBG 17.1%; Other GB 6.8%, p 0.01 Smoking was not associated with increased 30-day morbidity risk	Sleeve not included Unclear whether revisional surgery was included Model was validated; moderate discriminative ability (training set AUC 0.69, validation set AUC 0.66) Data from ACS NSQIP dataset
	Prospective	Not available			Prevalence smoking:	Revisional surgery was excluded

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
King, 2012 [46]	1945 69.9% RYGB, 25.2% LAGB, 2.6% LSG, 2.3% BGB/BPD 2 years		Preop: self-report, max 30 days prior Postop: questionnaire after 12 and 24 months	Prevalence of alcohol use disorder; pre- and postoperative associations with alcohol use disorder	Preop 2.2% Postop 1-year 7.9% Postop 2-year 9.3% Prevalence alcohol use disorder: Preop 7.6%; Postop 2-year 9.6% Smoking was associated with alcohol use disorder (OR 1.83 (1.22–2.76))	Unclear whether it concerned open/laparoscopic surgery Only cigarette smoking 44% RespR 19% LTFU after 2 years LABS-2 study [47]
Ramanan, 2012 [49]	Retrospective 32,889 51.1% LRYGB, 33.6% LAGB, 8.7% ORYGB, 3.5% other 1 month	Smoking within 1 year before surgery	Preop: medical record	30-day mortality risk	Preop smoking prevalence: 12.3% LRYGB 12.4%; ORYGB 14.8%; LAGB 11.8%; BPD 12.6%; VBG 8.4%; Other GB 8.9% Smoking was not associated with increased 30-day mortality risk	Sleeve not included Unclear whether revisional surgery was included Model was validated; high discriminative ability (AUCs ≥ 0.8) Data from ACS NSQIP dataset
Wood, 2012 [38]	Retrospective 2028 (L + O)RYGB 4 years	History of smoking	Preop: medical record	Constructing database	Preop smoking prevalence 11% Never 51% Quit 38% Unknown 8%	Preop program 6–12 months, goal 10% TWL <26% LTFU (no weight < 2 years in database) after 4 years Unclear whether revisional surgery was included
Arterburn, 2013 [50]	Retrospective 124 LRYGB, 392 ORYGB Veterans 12 months	Smoking within past year	Preop: medical record	TWL	Preop smoking prevalence: 13.4% Smoking was not related to TWL at 12 months	Veterans are older, more likely to be male, with lower incomes and greater comorbidity burden than the general bariatric population. 37% LTFU after 12 months
Conason, 2013 [11]	Prospective 100 LRYGB, 55 LAGB 2 years	Frequency of smoking cigarettes during last month on 10-point Likert scale (0 = never, 5 = occasionally, 10 = all of the time)	Preop: written questionnaire, 3 weeks prior to surgery Postop: written questionnaire 1, 3, 6, 12, 24 months	Prevalence smoking, alcohol and drug	No difference prevalence in smoking; preop 10.4%, 24-months postop 8.1% Increase in alcohol use after LRYGB compared to baseline (preop: 1.86, 1 year: 1.91 p 0.048, 2 years: 3.08 $p = 0.011$. No increase in alcohol use after LAGB	76% LTFU after 2 years RespR unclear No changes in complaints about reported substance use Only cigarettes included Unclear whether revisional surgery was included
Lent, 2013 [40]	Prospective 899 RYGB 34.9 months (SD 12.8)	Current: yes/no Amount of cig/day Amount of PY Previous: 100 cig lifetime	Preop: survey during preop preparation program Postop: survey per mail	Prevalence smoking, alcohol Relation with weight loss (EWL)	Preop smoking prevalence 19.4% . Postop smoking prevalence 14.8% Smoking preop and smoking postop were not related to EWL (median EWL 74.6%)	83% LTFU after 3 years RespR unclear Surveys were not anonymous Preop program 6–12 months, goal 10% TWL Unclear whether it concerned laparoscopic/open surgery Revisional surgery was excluded Cohort overlaps with previous study in Geisinger MC (Wood 2012) [38]
Benotti, 2014 [51]	Retrospective 185,315 51.9% (L + O)RYGB, 40.4% LAGB, 4.6% SG, 3.1% other 1 month	No: none, rare Yes: occasional, frequent	Preop: medical record	30-day mortality risk	Preop smoking prevalence: RYGB 5% Smoking was not related to 30-day mortality in RYGB patients Higher BMI, higher age, male, pulmonary hypertension, congestive	Timing of registration was not available 15% LTFU after 1 month Revisional surgery was excluded Cohort overlaps with previous studies in Geisinger MC (Wood 2012, Lent 2013) [38, 40]

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
					heart failure and liver disease were associated with higher mortality rates	
Gordon, 2014 [48]	Retrospective 333 RYGB 44.4 months (19.7)	Daily tobacco consumption of any amount	Preop: medical record, assessment included self-report questionnaire	Association preop personality and psychosocial assessment with EWL	Preop smoking prevalence 15.2% Univariable association between smoking and higher EWL after 6 and 24 months, but not after 12 and 'last' observation. No multivariable association between smoking and EWL. Psychosocial variables and personality traits were associated to EWL	Revisional surgery was excluded. Unclear whether it concerned open/laparoscopic surgery 74.3% RespR 54.7% LTFU after 2 years
Haskins, 2014 [3]	Retrospective 5749 open bariatric surgery, 35,696 laparoscopic bariatric surgery 1 month	One or more cigarette within 1 year prior to surgery	Preop: medical record	30-day complications	Preop smoking prevalence: not available Significant effects of smoking on morbidity (OR(95CI)) Organ space infection 1.45 (1.08–1.94) Prolonged intubation 1.82 (1.26–2.63) Pneumonia: 1.90 (1.42–2.54) Reintubation 1.62 (1.12–2.34) Sepsis 1.49 (1.11–2.00) Shock: 1.78 (1.16–2.74) Length of stay > 7 days 1.37 (1.12–1.67)	Cigar, pipe, tobacco chewing excluded Unclear whether revisional surgery was included Data from ACS NSQIP dataset Also results available for open and laparoscopic surgery separately
Still, 2014 [41]	Retrospective 2444 (L + O)RYGB 3 years	Smoker: current or history of smoking (≥ 100 cig)	Preop: medical record	Relations with EWL	Preop smoking prevalence: not available No history of smoking was related to 4.8% less EWL at 36 or more months after surgery (mean EWL 61.3%, SD 26.9)	40% LTFU after 3 years Preop program 6–12 months, goal 10% TWL Patients must be tobacco free for at least 6 months prior to surgery, documented by serum nicotine level. Cohort overlaps with previous studies in Geisinger MC (Wood 2012, Lent 2013, Benotti 2014) [38, 40, 51]
Coblijn, 2015 [34]	Retrospective 350 LRYGB 41 months (range 24–71)	Not available	Preop: medical record	Marginal ulcers	Preop smoking prevalence 20.6% Preop smoking related to marginal ulcer development; OR 2.85 (1.03–7.84)	39% of patients with marginal ulcer were smoker vs 19.3% without marginal ulcer, p 0.019 Revisional surgery was included 0% LTFU
Maniscalco, 2015 [42]	Prospective 28 IB, 30 LAGB, 5 LRYGB, 15 LSG 12 months	Smoking at least 10 cigarettes per day	Written questionnaire, < 1 month before intervention, 3, 6, 12 months after intervention	Smoking habit after intervention for morbid obesity in smokers weight loss (BMI reported)	Quitting rates 12 months after intervention: IB 14%, LAGB 3%, RYGB/LSG: 5%. No difference in weight loss between quitters and persistent smokers. No differences in quitting rate between intervention groups after 12 months. No correlation between weight loss and amount of cigarettes.	Exclusion of non-smokers and smokers smoking less than 10 cig per day. Suggestion to stop smoking, but no specific smoking cessation program Questions on smoking: initiation age, duration, number of cigarettes, cessation attempts, Fagerstrom test. During follow-up: number of cigarettes and reasons for quitting Weight loss was not further described. BMI pre- and post-intervention was reported.

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
						Unclear whether revisional surgery was included. RespR and LTFU not reported.
Mitchell, 2015 [56]	Prospective 201 RYGB 3 years	Current/recent	Preop: self-report	Prevalence of addictive behaviors	Preop smoking prevalence: 8.0% 8–18.4% develops alcohol use disorder after 3 years depending on criteria used	Preop smoking prevalence in patients not included 19.1% 74.6% RespR 17% LTFU after 3 years Unclear whether it concerned open/laparoscopic surgery, banded RYGB included, revisional surgery was excluded Subgroup of LABS-2 study [47]
Moser, 2015 [17]	Retrospective 184 LSG 22 months (SD 7)	Medical chart yes/no/former HSI (only postoperative)	Preop: medical record Post: telephone	Prevalence smoking; Association EWL	Preop smoking prevalence 33.7%. Former smoking: 31.0% Never smoking: 35.3% Postop prevalence smoking: 43.3% Former smoking preop: no one relapsed after surgery Never smoking preop: no one started postop. Stopped smoking after surgery 20.6% Smoking pre/post nor heaviness of smoking is related to EWL (24 months EWL 74%, SD 22)	47% LTFU 24 months Unclear whether revisional surgery was included
Mitchell, 2016 [16]	Prospective 1670 (L + O)RYGB, 548 LAGB 36 months	Never, always, stopped, started, sometimes, initially yes/no	Pre and postop: self-report	Prevalence smoking; predictors TWL	Preop smoking prevalence: RYGB: Smoking 1.2% Never 89.1% Other 9.7% LAGB: Smoking 1.4% Never 91.9% Other 6.7% Postop prevalence smoking RYGB Never 89.1% Always 0.8% Other 10.1% LAGB: Never 91.9% Always 0.4% Other 7.7% TWL RYGB: Never smoker: − 31.0% (0.3) Always smoker − 34.8% (1.7) p 0.02 TWL LAGB: Smoking behavior resulted not in significant difference TWL.	49.7% LTFU at 36 months (information on smoking and/or weight missing) For RYGB, the behavioral changes that resulted in a significant difference in percent weight change are eating or drinking meal replacements, keep eating when feeling full, eating continuously during the day, binge eating, binge eating disorder, loss of control eating, alcohol use disorder, and smoking. Revisional surgery was excluded. In manuscript, more specific subgroups reported in category other Cohort LABS-2 study [47]

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
Wood, 2016 [37]	Retrospective 1145 RYGB 9.3 years	History of smoking	Preop: medical record	Preop factors associated with long-term TWL	History of smoking was related to 2.8% more TWL (mean TWL 22.5% (SD 13.1))	29.7% LTFU after 9 years 6-month preop program, goal 10% TWL Unclear whether it concerned open and/or laparoscopic surgery. Revisional surgery was excluded Cohort overlaps with previous studies in Geisinger MC (Wood 2012, Lent 2013, Benotti 2014, Still 2014) [38, 40, 51, 41]
Coblijn, 2017 [33]	Retrospective 1709 75.1% LRYGB, 6.4% LSG, 17.4% revisional LRYGB, 1.2% other > 12 months	Not available	Preop: medical record	Risk on complications	Preop smoking prevalence: 25.1% Smoking was not associated with increased risk of complications	Not validated Table 8 contains two different numbers on smoking; total 1457; sum yes plus no is 1657 Overlapping data and cohort with Coblijn 2015 [34]
Haskins, 2017 [12]	Retrospective 33,714 LSG 1 month	Smoker: last year prior to surgery at least one cigarette	Preop: medical record	Prevalence smoking; effect smoking on 30-day postoperative morbidity and mortality	Preop smoking prevalence 9.8% Smoking was associated with a composite morbidity event (4.3 versus 3.7%, OR 1.23 (1.01–1.48), serious morbidity event (0.9 versus 0.6%, OR 1.9 (1.25–2.89), and 30-day mortality (0.2 versus 0.1%, OR 4.51 (1.95–10.42)). Smokers were more likely to have unplanned reintubation, OR 1.88 (1.01–3.50)	The length of hospital stay, unplanned readmission, and readmission rates were comparable between the 2 groups Revisional surgery was excluded Data from ACS NSQIP dataset
Kedrin, 2017 [59]	Retrospective 348 63% LRYGB, 5% LSG, 4% LAGB, 28% ORYGB 60 months (37.2)	Not available	Before index colonoscopy: medical record	Association of bariatric surgery with proportion of colorectal adenomas	Prevalence of smoking: Bariatric surgery after colonoscopy: 16.75% Bariatric surgery ≥ 1 year before colonoscopy: 18.4% Bariatric surgery before index screening colonoscopy was associated with decreased proportions adenomas (OR 0.37 (0.19–0.69))	Index screening colonoscopy in patients without family history of colorectal cancer, before or after bariatric surgery
King, 2017 [57]	Prospective 2218 70.6% (L + O)RYGB, 24.9% LAGB, 4.3% other 7 years	Not available	Preop: self-report, max 30 days prior to surgery	Association with initiation/continuation of prescribed opioid use	Preop smoking prevalence: 12.4% RYGB: 13.7%, LAGB: 8.5%, Other: 13.3% Preop smoking was not associated with postoperative initiation or continuation of prescribed opioid use	27% LTFU after 7 years Only cigarette smoking Revisional surgery was excluded Cohort LABS-2 study [47] King 2012 reported different preop smoking prevalence (2.2%)
Pierik, 2017 [35]	Retrospective 1670 LRYGB; 118 LSG 33.5 months (range 6–95)	Not available	Preop: medical record	Explanation of abdominal complaints	Preop smoking prevalence: 41.5% No difference between smoking for explained vs unexplained abdominal complaints, nor for no abdominal pain vs pain	Revisional surgery was included Overlapping cohort with Coblijn 2015 and Coblijn 2017 [33, 34]
Cayci, 2018 [39]	Prospective 40 LSG 12 months	Not available	Preop: medical record	Lower urinary tract functions and urination volume	Preop smoking prevalence: 25%	Unclear whether revisional surgery was included.

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
					Preop non-smokers: postop improved lower urinary system functions (OAB-Q and urination volume) Preop smokers: postop improved OAB-Q score, no difference in urination volume	
Inadomi, 2018 [13]	Retrospective 49,772 49.8% (L + O)RYGB, 50.2% (L + O)SG 3 years	Never smoker: no history of smoking Former smoker: quit at least 1 year before operation Recent smoker: quit between 3 months–1 year before operation	Preop: Medical record	30-day complications EWL	Prevalence preop smoking: Recent 7.7% Former 33.4% Never 58.8% Serious complications: RYGB: Risk-adjusted rate 5.4% (recent smoker) vs 2.9% (never), p 0.04 Any complication: RYGB: Risk-adjusted rate: 11.5% never, 10.5% former, ($p < 0.05$) 14.3% recent (ns) Complication rates were not affected by smoking status in LSG EWL differed significantly between recent smokers (73.4%) and never smokers (69.7%) 24 months after surgery, but not any more after 3 years	3 months lower bound in definition "recent smoking" was dependent on policies regarding minimum length of smoke-free period preoperatively of 39 sites 82% LTFU after 3 years Data from MBSC, overlapping data Birkmeyer 2010 and Finks 2011 [43, 54]
Lent, 2018 [15]	Retrospective 2918 RYGB 7 years	History of smoking	Preop: medical record	Predictors for below/average/above average postoperative weight loss trajectories (TWL)	Preop smoking prevalence: 51.6% WL trajectories after 7 years: Above average WL 38.5% (7.37), average WL 24.06% (7.48) and below average WL 12.67% (8.41) Smokers were more likely to be in above average WL group compared to average and below average WL group	Preop program 6–12 months, goal 10% TWL 42.5% LTFU after 7 yrs. Unclear whether it concerned open or laparoscopic surgery. Revisional surgery was excluded. Cohort overlaps with previous studies in Geisinger MC (Wood 2012, Lent 2013, Benotti 2014, Still 2014, Wood 2016) [37, 38, 40, 41, 51]
Kowalewski, 2018 [14]	Retrospective 47 LAGB, 84 LSG LAGB 11.2 years (SD 1.2); LSG 8 years (7.1–10.7)	Not available	Preop: medical record Postop: online survey	Prevalence smoking; EWL	Preop smoking prevalence LAGB 51%, LSG 62% Postop smoking prevalence: LAGB 43%, LSG 33% In both surgery groups: no difference in EWL	Qualification for surgery: encourage to cease smoking 6 months prior to the surgery Revisional surgery was excluded 39.9% LTFU
Signorini, 2018 [53]	Retrospective 184 LSG 80.7 months (SD 7.3)	Medical record yes/no/former HSI (only postoperative)	Preop: medical record Postop: Telephone	Prevalence smoking; EWL	Postop prevalence smoking: 27.5% 20.7% preop smokers stopped postop 14.7% preop ex-smokers relapsed Smoking pre/post nor heaviness of smoking was related to EWL	45% LTFU after 81 months Unclear whether revisional surgery was included Same cohort as Moser 2015 with longer follow-up [17]
Spaniolas, 2018 [52]	Retrospective 35,074 (L + O)RYGB 10 years	Not available	Preop: medical record	Complication/marginal ulcers	Preop smoking prevalence: 12.7% 17.8% with preop history smoking developed marginal ulcer within 8 years	Prevalence of preoperative tobacco use (14.6%) in table is different from other numbers on smoking in manuscript.

Table 6 (continued)

Author, year of publication	Description study (number of patients, type of surgery, follow-up)	Definition of smoking	Timing and method of registration	Outcome measures	Conclusions	Comments
					Tobacco use was associated with complications HR 1.56 (1.41–1.73)	Exclusion for analysis of in-hospital deaths Unclear whether revisional surgery was included 95.7% LTFU after 9 years Similar data and cohort as Altieri 2017, not reported in table [58]

Cig cigarette(s), *EWL* excess body weight loss, *LTFU* loss to follow-up, *RespR* response rate, *TWL* total weight loss, *WL* weight loss, Type of surgery/procedure: *BGB* banded gastric bypass, *BPD* biliopancreatic diversion with switch, *DS* duodenal switch, *IB* intra-gastric balloon, *LAGB* laparoscopic adjustable gastric band, *LGBP* laparoscopic gastric bypass procedure, *(L/O)RYGB* (laparoscopic/open) Roux-en-Y gastric bypass, *(L/O)SG* (laparoscopic/open) sleeve gastrectomy, *VBG* vertical banded gastroplasty, *Questionnaires*: *HIS* Heavy smoking index. Questionnaire categorizing smoking in "heavy smoker, moderate smoker and light smoker" depending on the amount of cigarettes per day and the time after waking taking first cigarette; OAB-Q OverActive Bladder-Questionnaire (higher score means more complaints), *Datasets*: *MBSC* Michigan Bariatric Surgery Collaborative, a regional consortium of 25 hospitals and 62 surgeons performing bariatric surgery in Michigan. ACS *NSQIP* American College of Surgeons National Surgical Quality Improvement Program data set. Nationally validated, risk-adjusted, outcomes-based clinical registry program to measure and improve the quality of surgical care, that includes more than 617 hospitals in the USA, 62 hospitals in Canada and 8 hospitals in Middle East region

In addition, reporting and evaluation of current policies on smoking cessation and intervention studies on the effects of smoking cessation before and after bariatric surgery are warranted.

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Compliance with Ethical Standards

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

Ethical Statement All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. This study was approved by the Institutional review board.

Informed Consent Statement Informed consent was obtained from all individual participants included in the study.

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