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ORIGINAL CONTRIBUTIONS

Are Geographical Health Accessibility and Socioeconomic Deprivation Associated with Outcomes Following Bariatric Surgery? A Retrospective Study in a High-Volume Referral Bariatric Surgical Center

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Abstract

Purpose Few studies have evaluated the association between non-clinical determinants (socioeconomic status and geographic accessibility to healthcare) and the outcomes of bariatric surgery, with conflicting results. This study aimed to evaluate this association.

Methods The medical records of 1599 consecutive patients who underwent either laparoscopic Roux-en-Y gastric bypass or laparoscopic sleeve gastrectomy between June 2005 and December 2017 were retrieved. All relevant data, including patient characteristics, biometric values before and after surgery, related medical problems, surgical history, medications, and habitus, for each patient were prospectively collected in a database. Logistic regressions were used to assess the influence of non-clinical determinants on surgical indications and complications. Multilevel linear or logistic regression was used to evaluate the influence of non-clinical determinants on long-term %TWL and the probability to achieve adequate weight loss (defined as a %TWL > 20% at 12 months).

Results Analysis of the 1599 medical records revealed that most geographically isolated patients were more likely to have undergone laparoscopic Roux-en-Y gastric bypass (odds ratio: 0.97; 95% confidence interval: 0.94 to 0.99; $P = 0.018$) and had a greater likelihood of adequate weight loss (β: 0.03; 95% CI: 0.01 to 0.05; $P = 0.021$). Conversely, socioeconomic status (measured by the European Deprivation Index) did not affect outcomes following bariatric surgery.

Conclusion Geographical health isolation is associated with a higher probability to achieve adequate weight loss after 1 year of follow-up, while neither health isolation nor socioeconomic deprivation is associated with post-operative mortality and morbidity. This results suggests that bariatric surgery is a safe and effective tool for weight loss despite socioeconomic deprivation.

Keywords Bariatric surgery · Weight loss · Health accessibility · Socioeconomic factors

Introduction

Obesity is a global public health problem with increasing prevalence worldwide [1]. In France, excess weight affects nearly half of the population [2]. Bariatric surgery is considered the most effective treatment for severe obesity, in terms of long-term weight loss maintenance and control of obesity-related medical problems [3, 4]. Bariatric surgery, such as laparoscopic Roux-en-Y gastric bypass (LRYGB) or laparoscopic sleeve gastrectomy (LSG), carries a very low or low risk of post-operative complications, including those leading to reintervention and even death [5].

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Several studies have highlighted socioeconomic disparities in access to bariatric surgery centers. It has been suggested that the likelihood of obtaining bariatric surgery is negatively correlated with male sex, low income, low education level, ethnicity, and insurance status [6–9]. However, few studies have examined the impact of socioeconomic status and geographical accessibility to healthcare on the early and long-term outcomes of bariatric surgery, with conflicting results.

Although there is evidence that individuals living closer to healthcare facilities use these at higher rates than those who live further away (distance decay association), it is not clear how this impacts health outcomes [10]. Isolated populations, such as rural populations, are particularly vulnerable and more inclined to experience higher rates of obesity and negative health outcomes [11]. These populations may also have more limited access to obesity treatment and specifically, bariatric surgery, or may experience poorer results post-surgery [12].

Moreover, several socioeconomic factors may affect postoperative complications and long-term results. In a Swedish registry-based cohort study, Stenberg et al. showed that socioeconomic factors (being divorced or widowed, receiving disability pension or social assistance, and being a first- or second-generation immigrant) affect early and late surgical outcomes [13]. In a study involving a single Veterans Affairs hospital, Carden et al. found that individuals residing in low-socioeconomic status areas had significantly lower weight loss than low-mid- and mid-high-income patients, regardless of sex, ethnicity, age, and distance from the hospital [14]. However, results on the influence of socioeconomic status (assessed by heterogeneous indicators) and weight loss are still conflicting. Using insurance status as an indicator of socioeconomic status, in a US population, Akkary et al. and Durkin et al. did not find an association [15, 16].

The aim of this study was to assess whether geographical health accessibility and socioeconomic deprivation influence early and long-term outcomes after bariatric surgery in a high-volume referral bariatric surgical center.

Methods

Study Design

Data were collected from a prospectively maintained database of patients who underwent primary laparoscopic bariatric surgery between June 2005 and December 2017 (to reach at least 24 months of follow-up) in our specialized and accredited bariatric center. The medical records of 1599 consecutive patients were analyzed.

All indications for bariatric surgery were assessed using the International Federation for the Surgery of Obesity and Metabolic Disorders criteria [17] and the recommendations of the French High Authority of Health (HAS). The criteria were that patients with BMI $\geq$ 35 with at least one associated medical problem listed by the HAS could benefit from surgical treatment, as well as patients with BMI $\geq$ 40 with or without associated medical problems.

Surgical Technique

All surgical procedures were standardized in our center. The surgical techniques used for this study have been previously described in the literature [18–20].

Data Collection

All relevant data for each patient were prospectively collected. Patient characteristics (sex and age), biometric values before and after surgery (weight, height, body mass index [BMI], percentage of total weight loss [%TWL]), associated medical problems (diabetes, hypertension, sleep apnea, dyslipidemia etc.), the American Society of Anesthesiologists (ASA) physical status classification system score, surgical history, current medication, and patient habitus were retrieved.

The post-operative data recorded included early and late post-operative complications, length of hospital stay, the rate of emergency room visits after discharge, and the rate of rehospitalization and reintervention. We considered surgery-related morbidity to be any complication resulting from the surgical procedure, such as anastomotic leakage, peritonitis, intraperitoneal bleeding, anastomotic bleeding, or any other event directly caused by the surgery. All complications were stratified according to the Clavien–Dindo scale [21], with a score $\geq$ 3 being considered as a severe complication. Readmission rate was defined as unplanned hospitalization after discharge from the bariatric care unit within the 90-day post-operative period.

Outcomes in weight control were evaluated according to follow-up weight, BMI, and %TWL. The %TWL was calculated according to the following formula: [(surgery weight − follow-up weight)/surgery weight] × 100.

Outcomes

The main objective was to assess the influence of non-clinical determinants on the early and long-term outcomes of bariatric surgery.

Early complications were defined as those occurring until post-operative day 90 or at any time during the primary hospital stay [5, 22]. Late complications were defined as those occurring > 90 days after surgery and included complications of any kind (e.g., urinary, pulmonary, vitamin deficiencies, eating disorders, abdominal pain, etc.). The %TWL was calculated at each follow-up surgical consultation and used as the repeated outcome variable in our models to assess the long-term weight loss. Adequate weight loss was defined as a %TWL > 20% at 12 months according to the literature [23–25].

Follow-up

All patients were assessed as part of a surgical routine follow-up program in the outpatient clinic and were seen according to a regular schedule at 1, 3, 6, 12, 18, and 24 months post-operatively. Thereafter, patients were seen annually.

Deprivation Index

The measurement of socioeconomic status remains challenging. Unfortunately, in most countries, medical files do not contain comprehensive socioeconomic data. Therefore, for decades, the deprivation ecological index has been widely used as a surrogate for the lack of individual data, particularly in the UK and USA [26].

Deprivation was assessed using the French version of the European Deprivation Index (EDI, 2011) [27]. The EDI is an aggregated composite index of deprivation in the area of residence, constructed by selecting fundamental needs associated with both objective and subjective poverty based on patients' home address. For all cases, the patients' home addresses were geolocated using Geographic Information Systems and were assigned to an Ilots Regroupés pour l'Information Statistique (IRIS) unit, which is the smallest geographical area defined by the Institut National de la Statistique et des Etudes Economiques for which census data are available. The French version of the EDI was used to assign a deprivation score to each IRIS. This score was then divided into five national quintiles. As the EDI is an ecological index, patients were stratified according to the deprivation of each area. The first quintile represented the richest patients and the fifth the poorest. In this study, the fourth and fifth quintiles were considered as "most socioeconomically deprived," and the remaining three (quintiles 1, 2, and 3) were considered as the "least socioeconomically deprived."

The use of the EDI may result in misclassification (i.e., the ecological bias). However, in addition to the effect of individual socioeconomic characteristics, the neighborhood analysis has shown that socioeconomic environment may be important [28, 29]. The EDI captures, in part, this contextual effect.

Geographical Health Accessibility Index

We used a health accessibility index, the Spatial aCcessibility multiscALar (SCALe) index, to estimate accessibility to health care for each patient [30]. This multiscalar index, based on the Permanent Facilities Database provided by the French Geographic National Institute, aims to highlight areas with cumulative health disadvantages. For each residential area (3 million for France mainland), 11 indicators representing access to primary care are calculated. These indicators (including distance to a general practitioner, to nurses, and to a pharmacist) are weighted according to the availability of each resource. Finally, combined with data on health indicators such as the incidence, fatality or mortality of a given pathology, or the effects of health screening, this multiscale index can be used to measure the influence of geographical accessibility on the health status of the population.

In this study, the SCALe index is used as a continuous variable to assess the impact of geographical health accessibility on each outcome. Its values, which are centered to zero, vary from negative to positive values (− 15.71 to 22.18). As the score of the SCALe index is increased (towards the most positive values), the geographic isolation increases. Thus, an increase in the index corresponds to an increase in geographical isolation.

Statistical Analyses

Chi-square and Fisher's exact tests were used to identify statistically significant differences for descriptive comparisons between the two groups of the EDI quintiles. $P < 0.05$ was defined as statistically significant.

The effects of clinical variables, socioeconomic status, and geographical health accessibility on the choice of surgical procedure (LRYGB versus LSG) and early and late complications were analyzed with univariable and multivariable logistic regression. The least socioeconomically deprived EDI group (quintiles 1, 2, and 3) was used as the reference category for all analyses.

Multilevel mixed-effects linear and logistic regressions were used to determine the statistical significance of socioeconomic inequalities and geographical health accessibility with repeated outcome measures. We created mixed models including repeated measures with a random intercept to determine if the EDI quintiles and SCALe index were associated with long-term %TWL or with the probability to achieve adequate weight loss at different follow-up times.

Each variable was tested in a univariable mixed model. All variables that were individually and significantly associated with each outcome were further assessed in a multivariable model using backward selection ($P < 0.2$). The EDI quintiles, SCALe index, sex, and age were forced in the multivariable model. The final model included all significant variables in the intermediate multivariable model.

To check the hypothesis of linearity due to the inclusion of the scale index in a continuous form, we used a four-node cubic spline model. $P = 0.05$ was considered as significant in the final model. All statistical analyses were performed with Stata/SE version 13 (StataCorp, College Station, TX, USA).

Results

Demographic and Clinical Characteristics

Between June 2005 and December 2017, surgeons performed consecutive primary laparoscopic bariatric surgery on 1599 patients. The demographic characteristics and clinical factors of the population were divided into quintiles 1, 2, and 3 (less deprived areas) and quintiles 4 and 5 (more deprived areas) and were compared (Table 1).

Geographical Health Accessibility and Social Deprivation

More deprived areas were significantly associated with higher biometric values (pre-operative weight and excess weight, and pre-operative BMI). They were less isolated from healthcare services. No significant difference was observed between the two quintile groups regarding sex, ASA score, related medical problems (current smokers, with diabetes, hypertension, dyslipidemia, and sleep apnea), or bariatric surgical procedures (LSG and LRYGB) (Table 1).

Surgical Indications (Table 2)

Table 2 shows the association between socioeconomic status and geographical health accessibility and surgical indication using logistic regression (with LRYGB as reference). There was no significant difference between less deprived areas and more deprived areas adjusted by age, sex, year of surgery, related medical problems, and pre-operative BMI.

In the univariable and multivariable analyses, the most geographically isolated patients ($P = 0.018$), patients with pre-operative BMI < 49.9 (P trend < 0.001) and with diabetes ($P < 0.001$) were more likely to undergo LRYGB. Meanwhile, significantly more male patients ($P < 0.001$) and patients with BMI > 49.9 (P trend < 0.001) underwent LSG.

Morbidity and Mortality (Table 3)

All procedures were performed laparoscopically without conversion. No deaths were observed at 90 days. Overall, early post-operative complications occurred in 330 patients (20.6%), with severe post-operative complications (Clavien Dindo scale ≥ 3) occurring in 75 patients (4.7%). At an average follow-up of 45.6 months, 634 patients had late complications (39.6%), with severe complications occurring in 196 (12.2%) patients, according to the Clavien–Dindo scale. The associations between geographical health accessibility or socioeconomic status and early or late complications using logistic regression are summarized in Table 3.

Early Complications. Socioeconomic deprivation (OR: 0.87; 95% CI: 0.67 to 1.14; $P = 0.329$) and geographical health accessibility (OR: 0.97; 95% CI: 0.95 to 1.00; $P = 0.067$) were not associated with early complications either in the univariable or multivariable analysis.

In the multivariable analysis, smoking ($P = 0.008$) and diabetes ($P = 0.028$) were significantly associated with early post-operative complications (within 90 days after surgery).

Performing a subgroup analysis by type of surgery, socioeconomic deprivation was not associated with early complications neither after LRYGB ($P = 0.065$) nor after LSG ($P = 0.297$). Geographical health accessibility was not associated with early complications after LSG ($P = 0.708$). However, after LRYGB the most isolated patients had a higher rate of early complications ($P = 0.032$) (results not in the table).

Late Complications. Socioeconomic deprivation (OR: 0.88; 95% CI: 0.70 to 1.11; $P = 0.273$) and geographical health accessibility (OR: 1.00; 95% CI: 0.98 to 1.02; $P = 0.727$) were not associated with late complications either in the univariable or multivariable analysis.

In the multivariable analysis, surgery performed more recently was an independent protective factor of late complications ($P < 0.001$).

In the same subgroup analysis, socioeconomic deprivation ($P = 0.148$ after LRYGB and P = 0.798 after LSG) and geographical health accessibility ($P = 0.881$ after LRYGB and P = 0.641 after LSG) were not associated with late complications.

Weight Loss (Tables 4 and 5)

Time	1 month	6 months	1 year	2 years	5 years	12 years
Number of patients	1365	1116	1145	1051	620	32
Lost to follow-up %	14.6	30.2	28.4	34.3	61.2	97.9
Average %TWL	9.59	24.61	30.35	30.26	26.07	28.70
Average %TWL for LRYGB	9.71	25.32	31.42	31.85	27.63	29.82
Average %TWL for LSG	9.32	22.96	28.02	26.80	22.03	23.36

Negative β coefficients indicate lower long-term %TWL. Schematically, a significant variable with a negative β means that the patient lost less weight.

Table 1 Characteristics of patients ($n = 1599$) who underwent LRYGB or LSG, according to European Deprivation Index quintiles

Variables	EDI quintiles 1–3 ($n = 743$)		EDI quintiles 4 and 5 ($n = 846$)		*P* values
Sex					0.955
Female	577	77.7%	656	77.5%	
Male	166	22.3%	190	22.5%	
Age					**0.029**
Continuous(years), mean ± SD*	743	43.7 ± 0.4	846	42.5 ± 0.4	
Preoperative bodyweight					**< 0.01**
Continuous (kg), mean ± SD*	743	118.1 ± 0.8	846	121.4 ± 0.8	
Preoperative excess weight					**< 0.01**
Continuous (kg), mean ± SD*	743	52.0 ± 0.7	846	54.8 ± 0.7	
Surgery BMI					**< 0.01**
< 40 kg/m^2	284	38.2%	282	33.3%	
40–49.9 kg/m^2	377	50.7%	428	50.6%	
> 49.9 kg/m^2	82	11.1%	136	16.1%	
ASA score					0.170
2	577	77.7%	621	73.4%	
3	166	22.3%	225	26.6%	
Former smoker					0.567
Yes	104	14.0%	127	15.0%	
No	639	86.0%	719	85.0%	
Diabetes					0.719
Yes	183	24.6%	215	25.4%	
No	560	75.4%	631	74.6%	
Hypertension					0.934
Yes	262	35.3%	300	35.5%	
No	481	64.7%	546	64.5%	
Dyslipidemia					0.311
Yes	162	21.8%	167	19.7%	
No	581	78.2%	679	80.3%	
Sleep apnea					0.201
Yes	291	39.2%	305	36.0%	
No	452	60.8%	541	63.9%	
Type of surgery					0.096
LRYGB	514	69.2%	552	65.2%	
LSG	229	30.8%	294	34.7%	
SCALe index					**< 0.001**
Continuous, mean ± SD*	725	− 1.62 ± 0.17	841	− 5.34 ± 0.15	
Lost to follow-up					
1 year	198	26.6%	202	23.9%	0.204
2 years	218	29.3%	282	33.3%	0.087
5 years	500	67.3%	601	71.0%	0.961
12 years	713	95.9%	796	94.1%	0.789

ASA American Society of Anesthesiologists, *BMI* body mass index, *LRYGB* laparoscopic Roux-en-Y gastric bypass, *LSG* laparoscopic sleeve gastrectomy, *n* number of patients, *EDI* European Deprivation Index, *SCALe* Spatial aCcessibility multiscALar, *SD* standard deviation

*Quantitative data treated as continuous variables

Long-term %TWL (Table 4). There was no significant difference in long-term %TWL regarding socioeconomic status and geographical health accessibility. The final multivariable model shows that LSG (in comparison with LRYGB) was associated with a decreased %TWL over 12 years of follow-up ($P < 0.001$). Moreover, older patients at surgery ($P < 0.001$), those with higher BMI (≥ 40) (P trend < 0.001), and those with diabetes ($P = < 0.001$) also experienced decreased %TWL.

Table 2 Univariable and multivariable logistic regressions of the influence of non-clinical determinants and clinical variables on the probability of receiving an LSG (with LRYGB as reference, n = 1599)

Variables	n	Percentage	Univariable analysis			Multivariable analysis*		
			OR	95% CI	P values	OR	95% CI	P values
EDI quintiles								
Less deprived areas	743	46.8%	Ref		0.096	Ref		0.951
More deprived areas	846	53.2%	1.19	0.97 to 1.47		1.01	0.78 to 1.29	
SCALe index								
Continuous	1566	97.9%	0.98	0.96 to 1.00	**0.044**	0.97	0.94 to 0.99	**0.018**
Sex								
Female	1240	77.5%	Ref		**< 0.001**	Ref		**< 0.001**
Male	359	22.5%	3.11	2.44 to 3.97		3.65	2.78 to 4.79	
Surgery age								
Continuous	1598	100%	1.00	0.99 to 1.01	0.873	1.00	0.99 to 1.01	0.973
Surgery BMI								
< 40 kg/m^2	570	35.7%	Ref		**< 0.001****	Ref		**< 0.001****
40–49.9 kg/m^2	808	50.5%	0.94	0.74 to 1.20		0.99	0.77 to 1.28	
> 49.9 kg/m^2	221	13.8%	5.37	3.83 to 7.51		6.57	4.54 to 9.51	
Year of surgery								
Continuous	1599	100%	1.03	0.99 to 1.07	0.162	1.09	1.04 to 1.14	**< 0.001**
Former smoker								
No	1368	85.5%	Ref		0.262			
Yes	231	14.5%	1.18	0.88 to 1.58				
Diabetes								
No	1197	74.9%	Ref		**0.047**	Ref		**< 0.001**
Yes	409	25.1%	0.78	0.61 to 0.99		0.56	0.42 to 0.75	
Hypertension								
No	1032	64.5%	Ref		**0.019**			
Yes	567	35.5%	1.29	1.04 to 1.60				
Dyslipidemia								
No	1268	79.3%	Ref		0.764			
Yes	331	20.7%	1.04	0.80 to 1.34				
Sleep apnea								
No	999	62.5%	Ref		**< 0.001**			
Yes	600	37.5%	1.55	1.26 to 1.92				

*Multivariable final model after backward selection, removing sleep apnea ($P = 0.524$), dyslipidemia ($P = 0.519$), former smokers ($P = 0.475$), and hypertension ($P = 0.297$)

**P value for trend

In the subgroup analysis by type of surgery, there was no significant difference in long-term %TWL regarding socioeconomic status ($P = 0.765$ after LRYGB and $P = 0.811$ after LSG) or geographical health accessibility ($P = 0.966$ after LRYGB and $P = 0.546$ after LSG).

Adequate Weight Loss (Table 5). In the univariable analysis, neither geographical health accessibility nor socioeconomic status was associated with adequate weight loss at 12 months of follow-up. When applying a multivariable model adjusting for deprivation status, sex, age, and other significant variables, the association between geographical health accessibility and the probability to achieve adequate weight loss became significant (β: 0.03; 95% CI: 0.01 to 0.05; $P = 0.021$). Conversely, the association between socioeconomic status and adequate weight loss remained insignificant.

In the multivariable analysis, independent risks factors of inadequate weight loss included old age ($P < 0.001$), hypertension ($P = 0.021$), and LSG ($P < 0.001$).

In the same subgroup analysis, there was no significant difference in long-term %TWL regarding socioeconomic status ($P = 0.960$ after LRYGB and $P = 0.495$ after LSG).

However, the association between geographical health accessibility and adequate weight loss became insignificant (β: 0.02; 95% CI: − 0.002 to 0.04; $P = 0.075$ after LRYGB and β: 0.04; 95% CI: − 0.01 to 0.09; $P = 0.140$ after LSG) because of the loss of power caused by the subgroup analysis.

Table 3 Multivariable logistic regressions of the influence of non-clinical determinants and clinical variables on early and late post-operative complications ($n = 1599$)

Variables	*n*	Percentage	Early complications			Late complications		
			Multivariable analysis*			Multivariable analysis**		
			OR	95% CI	*P* values	OR	95% CI	*P* values
EDI quintiles								
Less deprived areas	743	46.8%	Ref		0.329	Ref		0.273
More deprived areas	846	53.2%	0.87	0.67 to 1.14		0.88	0.70 to 1.11	
SCALe index								
Continuous	1566	97.9%	0.97	0.95 to 1.00	0.067	1.00	0.98 to 1.02	0.727
Sex								
Female	1240	77.5%	Ref		0.335	Ref		**< 0.001**
Male	359	22.5%	0.86	0.63 to 1.17		0.59	0.45 to 0.78	
Surgery age								
Continuous	1599	100%	1.00	0.98 to 1.01	0.598	0.99	0.98 to 1.00	0.470
Surgery BMI								
< 40 kg/m^2	570	35.7%						
40–49.9 kg/m^2	808	50.5%						
> 49.9 kg/m^2	221	13.8%						
Year of surgery								
Continuous	1599	100%	0.88	0.84 to 0.92	**< 0.001**	0.83	0.80 to 0.86	**< 0.001**
Type of surgery								
LRYGB	1069	66.8%				Ref		0.113
LSG	530	33.2%				1.21	0.96 to 1.52	
Former smoker								
No	1368	85.5%	Ref		**0.008**			
Yes	231	14.5%	1.56	1.12 to 2.18				
Diabetes								
No	1197	74.9%	Ref		**0.028**			
Yes	409	25.1%	1.40	1.04 to 1.89				
Hypertension								
No	1032	64.5%				Ref		**0.011**
Yes	567	35.5%				0.72	0.55 to 0.92	
Dyslipidemia								
No	1268	79.3%						
Yes	331	20.7%						
Sleep apnea								
No	999	62.5%						
Yes	600	37.5%						

*Multivariable final model after backward selection, removing hypertension ($P = 0.893$), dyslipidemia ($P = 0.809$), sleep apnea ($P = 0.545$), type of surgery ($P = 0.413$), and surgery BMI (***$P = 0.221$)

Multivariable final model after backward selection, removing diabetes ($P = 0.879$), former smokers ($P = 0.726$), sleep apnea ($P = 0.452$), surgery BMI (*$P = 0.355$), and dyslipidemia ($P = 0.282$)

***P value for trend

To verify the hypothesis of linearity due to the inclusion of the SCALe index in a continuous form in the regression model, we used a four-node cubic spline model (Fig. 1). Using this spline modelization in the last model, we found that the influence of geographic accessibility (aside from the SCALe index) quickly reached a plateau for a SCALe index equal to − 3. This influence was constant above this maximum.

Discussion

This study evaluated the association between non-clinical determinants, including geographical health accessibility and socioeconomic deprivation, and outcomes following bariatric surgery. The results suggest that geographical health isolation is associated with a higher probability to achieve adequate weight loss after 1 year of follow-up and

Table 4 Linear mixed model of %TWL from 1 month to over 12 years of follow-up after bariatric surgery in a referral bariatric center, 2005–2017 (*n* observed = 9147)

Variables	*n*	Percentage	Univariable analysis			Multivariable analysis*		
			*β***	95% CI	*P* values	*β***	95% CI	*P* values
EDI quintiles								
Less deprived areas	743	46.8%	Ref		0.649	Ref		0.645
More deprived areas	846	53.2%	−0.17	−0.92 to 0.57		−0.17	−0.88 to 0.54	
SCALe index								
Continuous	1566	97.9%	0.03	−0.04 to 0.11	0.401	−0.01	−0.06 to 0.09	0.723
Sex								
Female	1240	77.5%	Ref		**<0.001**	Ref		**0.004**
Male	359	22.5%	−2.87	−3.75 to −1.98		−1.23	−2.06 to −0.4	
Surgery age								
Continuous	1599	100%	−0.13	−0.16 to −0.10	**<0.001**	−0.09	−0.13 to −0.07	**<0.001**
Surgery BMI								
<40 kg/m^2	570	35.7%	Ref		**0.001*****	Ref		**<0.001*****
40–49.9 kg/m^2	808	50.5%	1.07	0.26 to 1.88		−0.62	−11.67 to −8.55	
>49.9 kg/m^2	221	13.8%	−0.23	−1.40 to −0.94		−0.48	−20.74 to −15.97	
Type of surgery								
LRYGB	1069	66.8%	Ref		**<0.001**	Ref		**<0.001**
LSG	530	33.2%	−3.91	−4.69 to −3.13		−2.91	−3.67 to −2.15	
Year of surgery								
Continuous	1599	100%	−0.61	−0.74 to −0.48	**<0.001**	0.07	−0.04 to 0.20	0.220
Follow − up time								
Continuous	1599	100%	0.38	0.37 to 0.40	**<0.001**	0.38	0.37 to 0.40	**<0.001**
Former smokers								
No	1368	85.5%	Ref		0.090	Ref		**0.022**
Yes	231	14.5%	0.93	0.15 to 2.00		1.11	0.16 to 2.06	
Diabetes								
No	1197	74.9%	Ref		**<0.001**	Ref		**<0.001**
Yes	409	25.1%	−2.30	−3.14 to −1.46		−1.50	−2.30 to −0.69	
Hypertension								
No	1032	64.5%	Ref		**<0.001**			
Yes	567	35.5%	−2.21	−2.98 to −1.45				
Dyslipidemia								
No	1268	79.3%	Ref		**<0.001**			
Yes	331	20.7%	−2.54	−3.47 to −1.62				
Sleep apnea								
No	999	62.5%	Ref		**<0.001**			
Yes	600	37.5%	−2.41	−3.17 to −1.66				
Individual variance						61.73	49.99 to 76.22	

*Multivariable final model after backward selection, removing dyslipidemia ($P = 0.783$), hypertension ($P = 0.478$), and sleep apnea ($P = 0.372$)

**Negative β coefficients indicate lower long-term percent total weight loss

****P* value for trend

that neither socioeconomic deprivation nor health isolation is associated with post-operative mortality and morbidity. Although the most isolated patients were more likely to be treated with LRYGB, the level of socioeconomic deprivation did not influence the choice of surgical procedure. However, as shown in previous studies, LRYGB and LSG yield different results. Once stratified by type of surgery, some results became insignificant probably due to the loss of power caused by the subgroup analysis. In fact, coefficient variation was negligible. Evidence indicates that participants with higher and sustained weight loss were more likely to have a lower pre-operative BMI and were often

Table 5 Multilevel mixed-effects logistic regression of the probability to achieve adequate weight loss from 1 month to over 12 months of follow-up after bariatric surgery in a referral bariatric center (*n* observed = 6016)

Variables	*n*	Percentage	Univariable analysis			Multivariable analysis*		
			β**	95% CI	*P*values	β**	95% CI	*P*values
EDI quintiles								
Less deprived areas	743	46.8%	Ref		0.778	Ref		0.747
More deprived areas	846	53.2%	0.01	− 0.09 to 0.12		0.04	− 0.19 to 0.26	
SCALe index								
Continuous	1566	97.9%	0.01	− 0.01 to 0.01	0.435	0.03	0.01 to 0.05	**0.021**
Sex								
Female	1240	77.5%	Ref		**0.035**	Ref		0.835
Male	359	22.5%	− 0.14	− 0.27 to − 0.01		0.03	− 0.24 to 0.29	
Surgery age								
Continuous	1599	99.9%	− 0.01	− 0.02 to − 0.01	**< 0.001**	− 0.03	− 0.05 to − 0.02	**< 0.001**
Surgery BMI								
< 40 kg/m^2	570	35.7%	Ref		**< 0.235**			
40–49.9 kg/m^2	808	50.5%	− 0.01	− 0.12 to 0.11				
> 49.9 kg/m^2	221	13.8%	− 0.13	− 0.29 to 0.04				
Type of surgery								
LRYGB	1069	66.8%	Ref		**< 0.001**	Ref		**< 0.001**
LSG	530	33.2%	− 0.27	− 0.39 to − 0.15		− 0.56	− 0.80 to − 0.32	
Year of surgery								
Continuous	1599	100%	− 0.01	− 0.03 to 0.01	0.302	− 0.04	− 0.07 to − 0.004	**0.031**
Follow-up time								
Continuous	1599	100%	0.64	0.59 to 0.69	**< 0.001**	0.64	0.59 to 0.69	**< 0.001**
Former smokers								
No	1368	85.5%	Ref		0.178			
Yes	231	14.5%	0.10	− 0.05 to 0.25				
Diabetes								
No	1197	74.9%	Ref		**< 0.001**			
Yes	409	25.1%	− 0.23	− 0.35 to − 0.10				
Hypertension								
No	1032	64.5%	Ref		**< 0.001**	Ref		**0.021**
Yes	567	35.5%	− 0.24	− 0.35 to − 0.13		− 0.29	− 0.54 to − 0.04	
Dyslipidemia								
No	1268	79.3%	Ref		**0.006**			
Yes	331	20.7%	− 0.19	− 0.32 to − 0.05				
Sleep apnea								
No	999	62.5%	Ref		**0.010**			
Yes	600	37.5%	− 0.14	− 0.25 to − 0.03				
Individual variance						1.05	0.64 to 1.72	

*Multivariable final model after backward selection, removing surgery BMI (*P trend* = 0.971), sleep apnea (*P* = 0.746), dyslipidemia (*P* = 0.331), former smokers (*P* = 0.287), and diabetes (*P* = 0.244)

**Negative β coefficients indicate lower probability to achieve adequate weight loss

****P* value for trend

treated with LRYGB [31–33]. After adjusting for age, sex, year of surgery, associated medical problems, preoperative BMI, and type of surgery, these results highlighted that isolated patients had a higher probability of achieving adequate weight loss. This relationship, also known as the "distance bias association," indicates an association between patients living further away from healthcare facilities and better health outcomes/higher access rates to healthcare services [34–36]. This kind of relationship has been demonstrated in numerous studies, particularly in cancerology [10]. This

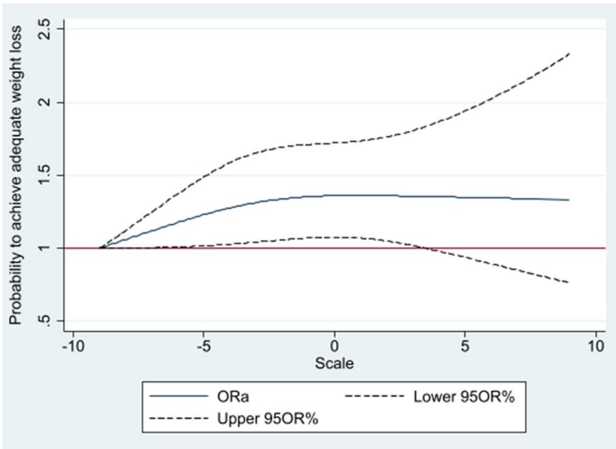

Fig. 1 Spline model representing the impact of the SCALe index on the probability to achieve adequate weight loss after bariatric surgery

association could be explained by selection bias (probably a better health condition) amongst the most isolated patients who may access bariatric surgery. Patients in better health would therefore be able to travel further to access care. Another potential explanation is that patients living farther away are healthier, live in an environment more conducive to weight loss, and are more motivated. Although this is not the main hypothesis, as it is less plausible, it cannot be ruled out. Further qualitative studies are required to confirm this hypothesis.

No mortality cases were recorded, which is consistent with the low mortality rate (0.2–0.3%) reported in recent registry-based cohort surveys [5, 13]. However, the overall morbidity rate (20.6%) is at the upper end of the scale for figures reported in the literature [5]. These results may be due to several reasons. First, contrary to previous studies [13], we did not assess morbidity rate at 30 days but at 90 days postoperatively because this time period appears insufficient to correctly predict surgical outcomes. Modern postoperative intensive care and perioperative management of surgical patients may reduce or postpone death from complications beyond 30 days, making 90-day outcomes more relevant in the modern era [5, 22]. Second, complications of any kind were recorded in the prospective database, unlike other studies generally focusing only on surgical and severe complications. This approach explains our relatively high rate of late complications. Finally, when the complications are classified according to severity [21], the observed figures are consistent with those in the literature, including at 90 days [5, 13].

To our knowledge, only one study has reported the significant impact of socioeconomic factors on post-operative complications [13], including lower income, residence in a large city, being divorced, a widow or widower, receiving social aid other than retirement pension, and being a first- or second-generation immigrant. Our findings contradict the results of Stenberg et al. [13], although more than half of the patients in this study were resident in the most deprived areas. A potential explanation for our findings is that a high-volume center, in conjunction with adherence to clinical pathways, not only improves outcomes but also reduces socioeconomic disparities.

The study has several strengths. Few studies have examined the impact of socioeconomic status and geographical health accessibility on early and long-term outcomes of bariatric surgery, and these revealed conflicting results [12, 37–39]. Most of the previous studies assessed short- or medium-term (< 3 years after surgery) results of bariatric surgery [40] or included a small number of patients [39]. Although recent studies had long-term follow-up, these focused primarily on clinical outcomes and co-morbid conditions rather than on predictors of long-term success, defined as high or sustained weight loss [41–43]. In contrast, our cohort benefits from a long-term follow-up with a relatively high number of patients ($n = 1599$) and low loss of follow-up rate 2 years after surgery (31.5%).

To assess weight loss, we applied multilevel mixed-effects models to account for the repeated measures of patient weight over time. Traditional approaches to assess differences in outcomes and differential associations with socioeconomic and territorial predictors have relied on a single time-point analysis, either through bivariate models or through regression models. To our knowledge, only two studies previously considered weight recorded as repeated measures by applying an adapted statistical method with conflicting results [39, 44]. Baldridge et al. found that ethnicity (black, mixed and missing combined in comparison with white) was associated with decreased %EWL from 1 year to over 9.5 years of follow-up [39]. However, this study involved a small number of patients ($n = 162$) and included only LRYGB. Finally, although previous studies focused on the impact of socioeconomics inequalities, little is known about the outcomes of bariatric surgery on "geographically health-isolated patients" who pursue and undergo surgery. To our knowledge, only 2 studies (and none with repeated measures) examined the relationship between geographical health accessibility and bariatric surgery outcomes in detail [12, 45]. A recent study investigated the effect of distance from high-volume Centers of Excellence without highlighting the effect of geographical health isolation on outcomes (30 days) and rate of readmission. However, only short-term outcomes were evaluated. Long-term outcomes according to %EWL or %TWL were not assessed [45]. Another study found no significant differences in weight loss and attendance at follow-up appointments between rural and non-rural individuals. However, the study was limited by a small sample size (and differing sample sizes between rural and non-rural groups) and a limited follow-up of 1 year [12].

When interpreting the results of this study, it is important to consider several limitations. Firstly, it is a retrospective monocentric review of prospectively collected data based on the experience of a single accredited French center. As this was a retrospective nonrandomized study, selection bias is possible.. The study was conducted in Lower Normandy, a northwest region of France. The Calvados area is one of the less deprived areas in this region; however, this area is the most represented in our sample population. Therefore, our results may underestimate socioeconomic inequalities and geographical health accessibility differences due to a lack of representativeness of our population. Another limitation concerns follow-up. Long-term follow-up of patients after bariatric surgery may be hampered by the collection of data solely through follow-up visits with the patient's bariatric surgeon, and the associated loss of follow-up amongst patients with treatment failure is a potential source of unmeasured bias in the analysis of long-term studies. Only national administrative data would provide a comprehensive view of patient outcomes. Unfortunately, in France, these data only concern hospital administrative data (age, sex, type of surgery) but do not contain any data on weight or comorbidities. Since education level, eating behavior, and nutritional status were not collected by the surgeons during the post-operative consultation, these variables were not available and limit the scope of the study, particularly with regard to the level of education. Finally, due to lack of data, we were unable to study the resolution of related medical problems, which is another key indicator in bariatric surgery.

In conclusion, this study shows that bariatric surgery is a safe and effective tool for weight loss despite socioeconomic deprivation, suggesting that all socioeconomic groups can benefit from it. However, the potential influence of geographical health isolation on bariatric surgical outcomes might suggest a disparity in access to referral bariatric surgical centers for the most isolated patients. Therefore, the creation of a multicentric observatory or national registry, as in other chronic diseases, should be encouraged to confirm and explain the mechanisms of potential geographical health disparities in bariatric surgery outcomes.

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Declarations

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

The requirement for patient consent was waived owing to the retrospective nature of the study. This study was declared to the French Data Protection Authority, CNIL (2204611v0).

Conflict of Interest The authors declare no competing interests.

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