Obesity Surgery
https://doi.org/10.1007/s11695-019-03730-w

ORIGINAL CONTRIBUTIONS

Alteration Pattern of Taste Perception After Bariatric Surgery: a Systematic Review of Four Taste Domains

Saeed Shoar[1,2] · Mohammad Naderan[2] · Nasrin Shoar[1,3] · Venkat R. Modukuru[1,4] · Habibollah Mahmoodzadeh[2]

Abstract

Background Efforts continue to understand the underlying mechanism of weight loss after bariatric surgery. Taste perception has shown to be a contributing factor. However, the alteration pattern in different taste domains and among bariatric procedures has not been sufficiently investigated.

Objectives To study the alteration pattern in the perception of four taste domains after different bariatric procedures.

Settings Private Research Institute, USA.

Methods A systematic review was conducted to pool available data in the literature on post-operative changes in the perception of sensitivity to four taste domains after Roux-en-Y gastric bypass (RYGB), laparoscopic sleeve gastrectomy (LSG), and adjustable gastric banding (AGB).

Results Our study showed that bariatric surgery is associated with significant change in sensitivity to all four taste domains especially salt taste, sweetness, and sourness. LSG patients showed an increased sensitivity to all four taste domains. However, RYGB patients had a variable alteration pattern of taste perception but more commonly a decreased sensitivity to sweetness and an increased sensitivity to salt taste and sourness. Additionally, AGB patients had a decreased sensitivity to sweetness, salt taste, and sourness.

Conclusion Bariatric surgery is associated with taste change in a way which results in less preference for high-calorie food and possibly reduced calorie intake. This may explain one of the mechanisms by which bariatric surgery produces weight loss. However, data are heterogeneous, the potential effect dilutes over time, and the alteration varies significantly between different procedures.

Keywords Taste perception · Bariatric surgery · Sleeve gastrectomy · Roux-en-Y gastric bypass · Adjustable gastric banding · Weight loss · Sweetness · Salt taste · Sourness · Bitterness

Introduction

Current obesity pandemic is the result of overconsumption of dense calorie food [1, 2] and underutilization of rigorous physical activity [3, 4]. Taste perception plays an important role in human appetite and satiety, food preference, calorie consumption, and eating behavior [5–8]. Alteration of taste perception and gustatory thresholds has been implicated as a potential treatment for obesity [9, 10]. However, little is known about such a taste change following bariatric surgery, especially its impact on the surgery-induced weight loss.

Bariatric surgery is the stand-alone treatment for morbid obesity and the only weight loss option with durable result [11]. Laparoscopic sleeve gastrectomy (LSG) and Roux-en-Y gastric bypass (RYGB) are the two most commonly performed procedures in bariatric surgery [12]. Despite significant improvement in technical profile and post-operative care in bariatric surgery [13], efforts still continue to investigate its mechanism of massive weight loss and durability of metabolic benefits.

There is only one systematic review of the literature on the gustatory changes following bariatric surgery [14]. However, this article has simplified its data synthesis to a narrative description of the included studies and has not

✉ Saeed Shoar
saeedshoar@ScientificWriting.org

1 Department of ScientificWriting, Division of Surgical Research, Shoar Research Institute, Houston, TX, USA

2 Cancer Institute, Imam Khomeini Hospital Complex, Division of Surgical Oncology, Department of Surgery, Tehran University of Medical Science, Tehran, Iran

3 Faculty of Medicine, Kashan University of Medical Science, Kashan, Iran

4 Faculty Surgeon, Department of Surgery, NYMC at Metropolitan Hospital Program, New York City, NY, USA

Published online: 02 February 2019

performed a pooled analysis. Our systematic review aims to pool available data in the literature on post-bariatric taste perception and analyze the alteration pattern of four main taste domains in patients undergoing different weight loss surgeries.

Methods and Materials

Study Design

A systematic review was designed according to the Cochrane Handbook for Systematic Reviews of Interventions [15] and performed in accordance with the items of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Fig. 1) [16]. An electronic literature review was conducted through September 2018. Two independent reviewers screened the titles and abstracts of the identified records for eligible articles. Any conflict in the study selection was resolved by the third investigator. Three reviewers extracted the data from the included studies for the variables of interest.

Search Protocol

An electronic search was performed in Medline/PubMed, Web of Science, Embase, and Scopus using the following combination of search terms: ("Taste change" OR "Taste alteration") AND ("RYGB" OR "Gastric bypass" OR "LSG" OR "Sleeve gastrectomy" OR "AGB" OR "Gastric banding").

Study Selection

Studies in English language comparing pre- and post-bariatric surgery taste perception in morbidly obese adults were eligible. Review articles, editorials, commentaries, case reports, and experimental studies were excluded. Full text of the eligible articles was accessed for quality assessment and data extraction. Data on the variables of

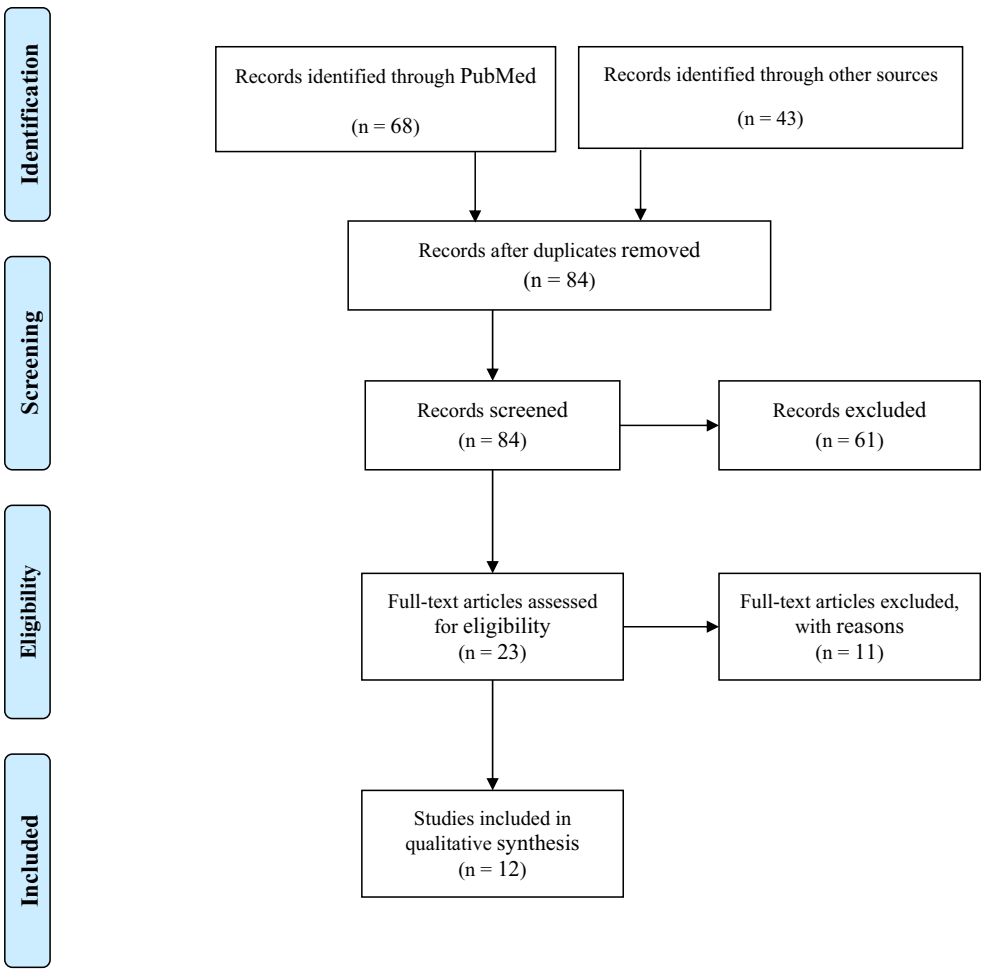

Fig. 1 PRISMA flowchart for our search strategy and study selection

interest were inserted into the study spreadsheet for further analysis.

Data Collection

The following information were obtained from the included studies: the first author's name; publication year; study type and sample size; demographics of the study patients (age, gender, and body mass index [BMI]); type of bariatric surgery; post-operative weight loss; taste measurement tool (questionnaire or liquid solutions); type of post-operative taste change including sweetness, salt taste, sourness, and bitterness; and the time of taste measurement after bariatric surgery.

Outcome Measure

The primary outcome for our systematic review was the incidence of post-bariatric surgery taste change, defined as an increase or decrease in perception of/sensitivity to four major tastes (sweetness, salt taste, bitterness, and sourness). The secondary outcome was the frequency of taste change across different weight loss surgeries including LSG, RYGB, and adjustable gastric banding (AGB).

Statistical Analysis

Pooled analysis was performed based on the reported frequency of each variable out of the total number of the events. Data are reported as number (n, %) and mean ± standard deviation (SD).

Results

Literature Review

Twelve studies encompassing a total of 899 patients who underwent bariatric surgery for morbid obesity were included [17–28]. The weight loss procedure was RYGB in 490 patients, LSG in 371 patients, and AGB in 38 patients. Patients' age ranged from 26.7 to 56.3 years old [19]. Preoperative BMI varied between 30 [19] and 72.6 kg/m^2 [18]. The amount of weight loss was reported between 20 and 83% of the total body weight (Table 1).

Overall Taste Sensitivity Change After Bariatric Surgery

Taste sensitivity change (Fig. 2) was measured at different time intervals after bariatric surgery from 1 month [24] to 120 months [20] post-operatively. The measurement scale was a questionnaire in 726 patients (80.75%) [20, 21, 25, 26, 28] and stimuli solution in 173 patients (19.25%) [17–19, 22–24, 27].

Post-operative Alteration in Sensitivity to Sweetness (Table 2)

Sweetness taste change was reported in 641 patients (RYGB, 411; LSG, 192; AGB, 38). Of these, 334 patients (52.1%) had an increased sensitivity to sweetness, 276 patients (43.1%) had a decreased sensitivity, and 31 patients (4.8%) showed no changes.

Post-operative Alteration in Sensitivity to Salt Taste (Table 2)

Salt taste change was reported in 483 patients (RYGB, 258; LSG, 187; AGB, 38). Of these, 308 patients (63.8%) had an increased sensitivity to salt taste, 144 patients (29.8%) had a decreased sensitivity, and 31 patients (6.4%) showed no changes.

Post-operative Alteration in Sensitivity to Sourness (Table 2)

Sourness taste change was reported in 338 patients (RYGB, 136; LSG, 184; AGB, 18). Of these, 234 patients (69.2%) had an increased sensitivity to sourness, 46 patients (13.6%) had a decreased sensitivity, and 58 patients (17.1%) showed no changes.

Post-operative Alteration in Sensitivity to Bitterness (Table 2)

Bitterness taste change was reported in 209 patients (RYGB, 43; LSG, 166; AGB, 0). Of these, 112 patients (53.6%) had an increased sensitivity to bitterness, 0 had a decreased sensitivity, and 45 patients (21.5%) showed no changes.

Comparison of Taste Sensitivity Change Across Different Bariatric Procedures (Table 3)

RYGB Patients

Taste sensitivity change after RYGB was reported in 411 patients in regard to the sweetness (152 patients with an increased sensitivity [37%], 236 patients with a decreased sensitivity [57.4%], and 23 patients with an unchanged sensitivity [5.6%]), in 258 patients in regard to the salt taste (122 patients with an increased sensitivity [47.3%], 113 patients with a decreased sensitivity [43.8%], and 23 patients with an unchanged sensitivity [8.9%]), in 136 patients in regard to the sourness (61 patients with an increased sensitivity [44.8%], 35 patients with a decreased sensitivity [25.7%], and 40 patients with an unchanged sensitivity [29.4%]), and in 43 patients in regard to the bitterness (6 patients with an increased sensitivity [13.9%], 0 patients with a decreased sensitivity, and 37 patients with an unchanged sensitivity [86%]).

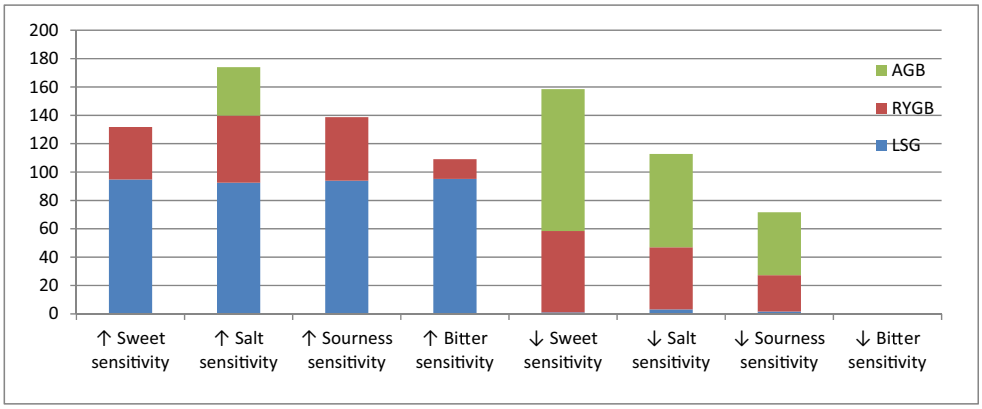

Fig. 2 Alteration of taste sensitivity after bariatric surgeries; RYGB:' Roux-en-Y gastric bypass; LSG: Laparoscopic sleeve gastrectomy; AGB: Adjustable gastric banding

LSG Patients

Taste change after LSG was reported in 192 patients in regard to the sweetness (182 patients with an increased sensitivity [94.8%], 2 patients with a decreased sensitivity [1.04%], and 8 patients with an unchanged sensitivity [4.2%]), in 187 patients to the salt taste (173 patients with an increased sensitivity [92.5%], 6 patients with a decreased sensitivity [3.2%], and 8 patients with an unchanged sensitivity [4.3%]), in 184 patients to the sourness (173 patients with an increased sensitivity [94%], 3 patients with a decreased sensitivity [1.6%], and 8 patients with an unchanged sensitivity [4.3%]), and in 166 patients to the bitterness (158 patients with an increased sensitivity [95.2%] and 8 patients with an unchanged sensitivity [4.8%]).

AGB Patients

Taste change after AGB was reported in 38 patients to the sweetness (38 patients with a decreased sensitivity [100%]), in 38 patients to the salt taste (13 patients with an increased sensitivity [34.2%] and 25 patients with a decreased sensitivity [65.8%]), in 18 patients to the sourness (8 patients with a decreased sensitivity [44.4%] and 10 patients with an unchanged sensitivity [55.5%]), and in 0 patients to the bitterness.

Discussion

Taste perception has been known as a determining factor in food selection, eating pattern, and total calorie intake [6]. High sensitivity to the sweet taste is variably associated with food reward and calorie intake [7, 8]. More consistently, high sensitivity to bitter taste causes food aversion and low calorie intake [29–32]. With these in mind, alteration of taste perception following bariatric surgery might explain the underlying mechanism for weight loss [9, 10]. Nevertheless, the majority of studies are centered on sweet and bitter tastes and few have elaborated on the possible role of sourness and salt taste.

Our systematic review investigated the alteration pattern of taste perception and sensitivity to four different taste domains after bariatric surgery including RYGB, SG, and AGB. In general, bariatric surgery patients had an increased sensitivity to all taste domains. However, data stratification based on different procedures showed that RYGB decreases the sensitivity to sweetness and increases the perception of salt taste and sourness. On the other hand, LSG patients had an increased sensitivity to all four taste domains. Patients who had an AGB showed a decreased sensitivity to sweetness, salt taste, and sourness.

The literature suffers a huge heterogenity on this subject; studies use different scales (questionnaire vs. chemical stimulants) to measure taste sensitivity, and there is not the same attention to all the four main taste domains. Additionally, taste sensitivity has rarely been investigated long enough post-operatively to reveal any potential link with weight loss durability. There is only one systematic literature review which has summarized mixed data of animal experiments and human studies on both smell and appetite change after bariatric surgery [14]. Although the included studies in that review article are very heterogeneous, there was a trend toward increased sensitivity to sweet taste and fatty stimuli post-operatively. However, the study did not elucidate the difference between different weight loss procedures.

Post-Bariatric Change of Sensitivity to Sweetness (Fig. 2)

Overall, 52.1% of the patients had an increased sensitivity to sweetness after bariatric surgery. The majority of this pattern was related to LSG with an increased sensitivity to the sweetness in 94.8% of the patients which can explain sweet food aversion and decreased calorie consumption. On the other hand, RYGB patients more commonly had a decreased sensitivity to sweetness (57.4%) than they did an increased sensitivity (37%) which may results in more craving for sweetened food. The same pattern was observed in AGB patients with a decreased sensitivity to sweetness in all of them.

Table 1 Characteristics of included studies reporting post-bariatric surgery taste perception changes

Author	Design	Sample size	Age (years)	Pre-operative BMI (kg/m^2)	Gender (M/F)	Total weight loss (%)	Taste measurement
Nance 2017	Cohort	8 LSG, 23 RYGB	26.7–52.6	39.4–62	4/27	16.1–23.5%	Taste stimuli (54.9–169 days)
Van Vuuren 2017	Prospective	106 LSG	31.28–52.72	44 ± 7.35	104/92	26 ± 5.88%	Questionnaire (4–8 months)
Altun 2016	Prospective	52 LSG	38.5 ± 9.4 (LSG)	45.8 ± 7.2	22/30	25% ± 7.1 (1 month); 43.9% ± 10.3 (3 months)	Taste stimuli (1 months and 3 months)
Ekmekcioglu 2016	Cohort	30 RYGB (or omega loop GB)	46.3 ± 10 (23–65)	43.2 ± 5.7 (30–51)	8/21	N/A	Taste stimuli (3 months)
Makaronidis 2016	Cross-sectional	155 LSG, 98 LRYGB	44.3 ± 1.1 (LSG); 46.5 ± 1.0 (LRYGB)	46.1 ± 0.6 (SG) and 44.7 ± 0.7 (LRYGB)	35/120 (LSG) and 19/79 (LRYGB)	21.2% ± 0.8 (LSG); 25.6% ± 0.9 (0.5–5 years) LRYGB	Questionnaire (LSG 593 ± 43 days) (LRYGB 769 ± 53 days)
Zerrweck 2016	Cohort	50 LSG, 104 RYGB	41.4 ± 10.2 (LSG); 41.1 ± 9.1 (LRYGB)	45.8 ± 8.3 (LSG); 43.3 ± 5.8 (RYGB)	19/31 (LSG); 16/88 (RYGB)	51.2% ± 20.6 (LSG); 74.1% ± 19 (LRYGB)	Questionnaire (LSG 10.5 ± 10.4 months) (LRYGB 11.5 ± 6.1 months)
Wang 2016	Case control	13 LRYGB	46.5 ± 9.3 (LRYGB)	43.1 ± 4.4	5/8 (LRYGB)	3.6 kg/m^2 BMI (1 month); 13.8 kg/m^2 BMI (1 year)	Taste stimuli (1 month, 1 year)
Graham 2014	Cohort	103 (LRYGB)	45 (LRYGB)	51	14/89 (LRYGB)	11–162 kg	Questionnaire (median of 19 months, range 1–120 months)
Pepino, 2014	Cohort	17 (RYGB), 10 (LAGB)	32.9–60.7	38–59	N/A	20% weight loss	Taste stimuli
Tichansky 2006	Cross-sectional	28 (LAGB), 82 (LRYGB)	N/A	N/A	N/A	N/A	Questionnaire
Burge 1995	Prospective case control	14 (RYGB)	38.4 ± 6 (RYGB)	60.8 ± 11.8 (RYGB)	6/8 (RYGB)	N/A	Taste stimuli (pre-operative, 6 weeks, and 12 weeks)
Scruggs 1994	Case control	6 (RYGB)	34.1 ± 3.2 (RYGB)	44.2 ± 2.9 (RYGB)	6F (RYGB)	15 kg (30 days); 25 kg (60 days); 32 kg (90 days)	Taste stimuli (baseline, 30 days, 60 days, and 90 days)

BMI, body mass index; *M:F*, male-to-female ratio; *LSG*, laparoscopic sleeve gastrectomy; *RYGB*, Roux-en-Y gastric bypass; *AGB*, adjustable gastric banding

Ghrelin plays a substantial role in the regulation of appetite and preference for consumption of food with a sweet taste [33, 34]. The plasma ghrelin decreases after LSG but increases following RYGB [35, 36]. Such an alteration pattern might explain the observed difference in the perception of sweet taste between the two procedures and subsequent craving for sweetened food. On the other hand, leptin has been shown to suppress sweet taste response of the enteroendocrine cells and subsequently modulate glucose absorption in the small intestine [37]. While decreased level of leptin following RYGB and LSG can result in consumption of foods with a high sugar content [35], craving for sweet food among stressed women has been contradictorily associated with an increased level of leptin [34].

Post-Bariatric Change of Sensitivity to Salt Taste (Fig. 2)

Overall, 63.8% of patients had an increased sensitivity to the salt taste after bariatric surgery. The majority of this pattern was related to LSG with an increased sensitivity to the salt taste in 94.8% of the patients. Moreover, RYGB patients more commonly had an increased sensitivity to salt taste (47.3%) than they did a decreased sensitivity (43.8%). However, an opposite pattern was observed among AGB patients with 65.8% of the patients showing a decreased sensitivity and 34.2% of the patients showing an increased sensitivity to the salt taste.

Current evidence is scarce on the hormonal regulation of the salt taste perception particularly in bariatric surgery patients [38, 39]. In a study of 38 non-obese normotensive Chinese individuals, Zhang et al. investigated the potential association between different salty diets and plasma ghrelin [39]. The study indicated that a diet with high-salt content is associated with an elevated level of fasting ghrelin and potentially linked with obesity. An animal experiment of rat gustatory signaling pathway implicated that sensitivity to salty taste was decreased in ghrelin-knockout mice compared with the wild-type mice [38]. Nevertheless, long-term data of Swedish obese subjects has shown a higher urinary salt excretion in RYGB patients compared with patients who had a restrictive procedure such as vertical banded gastroplasty [40]. The study also found a higher salt intake by patients of RYGB group than those of the pure restrictive procedure.

Post-Bariatric Change of Sensitivity to Sourness (Fig. 2)

Overall, 69.2% of the patients had an increased sensitivity to the sourness after bariatric surgery. The majority of this pattern was related to LSG with an increased sensitivity to sourness in 94% of the patients. Similarly, RYGB patients more commonly had an increased sensitivity to the sourness (44.8%).

Table 2 Comparison of post-operative taste perception changes between bariatric procedures

Author ↓	Sweetness		Salt taste		Sourness		Bitterness		Study conclusion
	LSG	RYGB	LSG	RYGB	LSG	RYGB	LSG	RYGB	
Nance 2017	8 ↔	23 ↔	8 ↔	23 ↔	8 ↔	23 ↔	8 ↔	23 ↔	No difference between procedures or at different intervals
Van Vuuren 2017	106 ↑	N/A	106 ↑	N/A	106 ↑	N/A	106 ↑	N/A	Intensity of sweet perception was more pronounced
Altun 2016	52 ↑	N/A	52 ↑	N/A	52 ↑	N/A	52 ↑	N/A	Improved gustatory sensitivity was significant in all 4 domains
Ekmekcioglu 2016	N/A	–	N/A	30 ↓	N/A	–	N/A	–	Salt threshold increased (salty perception decreased)
Makaronidis 2016	N/A	98 ↓	N/A	N/A	N/A	N/A	N/A	N/A	RYGB is associated with more taste change and weight loss than LSG
Zerrweck 2016	24 ↑, 2↓	62 ↑, 19↓	15↑, 6↓	36↑, 13↓	15↑, 3↓	31↑, 9↓	N/A	N/A	Taste change occurs soon after surgery (0–4.8 months) and no difference between procedures
Wang 2016	N/A	13 ↑	N/A	13 ↓	N/A	N/A	N/A	N/A	Reward center for taste in the brain shows decreased pleasure for sweatiness and increased pleasure for salty taste
Graham 2014	N/A	36↑; 41↓	N/A	31↑; 21↓	N/A	12↑; 10↓	N/A	N/A	Subjective changes after RYGB are very common and should be part of an informed consent after bariatric surgery
Pepino 2014	10 ↓ in AGB	17 ↓	10 ↓ in AGB	17 ↓	10 ↔ in AGB	17 ↔	N/A	N/A	No change in taste perception or sensitivity
Tichansky 2006	AGB: 28↓	55↓; 27↑	AGB: 15↓; 13↑	13↓; 55↑	AGB: 8↓; 0↑	16↓; 12↑	N/A	N/A	Although taste changes occur after bariatric surgery; procedural difference exist
Burge 1995 (tested sensitivity)	N/A	14↑	N/A	N/A	N/A	N/A	N/A	14 ↔	At 6 weeks after RYGB, patients tasted the food sweeter
Scruggs 1994 (tested sensitivity)	N/A	6↓	N/A	6↓	N/A	6↑	N/A	6 ↑	Weight loss after gastric bypass is associated with increased taste acuity
Total									

LSG, laparoscopic sleeve gastrectomy; *RYGB*, Roux-en-Y gastric bypass; *AGB*, adjustable gastric banding; *N/A*, not applicable

Table 3 Overall taste sensitivity change after different bariatric surgeries

Surgery		RYGB	LSG	AGB
Taste sensitivity				
Sweetness	Increased	152 (37%)	182 (94.8%)	0
	Decreased	236 (57.4%)	2 (1.04%)	38 (100%)
	Unchanged	23 (5.6%)	8 (4.2%)	0
Salt taste	Increased	122 (47.3%)	173 (92.5%)	13 (34.2%)
	Decreased	113 (43.8%)	6 (3.2%)	25 (65.8%)
	Unchanged	23 (8.9%)	8 (4.3%)	0
Sourness	Increased	61 (44.8%)	173 (94%)	0
	Decreased	35 (25.7%)	3 (1.6%)	8 (44.4%)
	Unchanged	40 (29.4%)	8 (4.3%)	10 (55.5%)
Bitterness	Increased	6 (13.9%)	158 (95.2%)	0
	Decreased	0	0	0
	Unchanged	37 (86%)	8 (4.8%)	0

However, 86% of AGB patients had an unchanged sensitivity to the sourness.

Perception of sourness occurs with a decrease in intracellular pH of acid-sensing cells in the neural pathway of sour taste [41]. Very little is known about sour taste sensitivity and weight change in human [5]. A cross-sectional study on the association between taste sensitivity and body weight reported an age-dependent pattern with sourness and bitterness [42]. The study showed a higher sensitivity to sour and bitter taste in patients with lower body weight. In another study of taste acuity in obese adolescents during a weight reduction program, a higher sensitivity to taste stimulants including citric acid was associated with less acceptability of healthy foods such as fruits and vegetables [43]. Interestingly, a randomized controlled trial has shown that adding sour cherry pomace to muffins has a dose-dependent beneficial effect in managing glucose levels, satiety, and subsequent energy intake in healthy individuals when compared to the plain muffin [44]. Although the effect arises at large from a modified amount of plain flour in bakery, the sour taste might play a role in regulation of the appetite, satiety, and total energy intake.

Post-Bariatric Change of Sensitivity to Bitterness (Fig. 2)

Overall, 53.6% of the patients had an increased sensitivity to bitterness after bariatric surgery. The majority of this pattern was related to LSG with an increased sensitivity to bitterness in 95.2% of the patients. On the other hand, RYGB patients more commonly had an unchanged sensitivity to the bitterness (86%) than they did an increased sensitivity (13.9%). There was no report regarding the sensitivity change to the bitterness in AGB patients.

Data of animal studies has shown that the interaction of bitter compounds with enteroendocrine cells in the small intestine increases cholecystokinin release [45]. On the other hand, jejunoileal bypass has been associated with an increase in cholecystokinin level [46, 47]. Although increased cholecystokinin plays a role in appetite regulation and the potential weight loss [48, 49], it is not known if post-operative change of bitterness sensitivity is a cause for or a result of alteration in cholecystokinin level.

Limitations

There is a huge heterogeneity in the literature on the post-operative changes of taste sensitivity after bariatric surgery. Studies do not utilize a standardized scale to measure the taste sensitivity. Additionally, timeline for the post-operative taste measurement differs variably across the studies. On the other hand, data needs to be scrutinized exclusively according to the weight loss procedure.

Conclusion

Roux-en-Y gastric bypass is associated with a decreased sensitivity to sweetness but an increased sensitivity to salt taste and sourness. Sleeve gastrectomy more commonly increases the sensitivity to all four tastes. However, patients with adjustable gastric banding had a decreased sensitivity to sweetness, salt taste, and sourness. Due to the huge heterogeneity in the literature, any conclusion on the effect of bariatric surgery on post-operative taste sensitivity is preliminary. Metabolic procedures such as RYGB and LSG result in a more pronounced alteration of taste sensitivity to salt taste and sweetness which might explain their superior weight loss outcome than that of pure restrictive procedures such as AGB.

Compliance with Ethical Standards

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

Statement of Informed Consent Not applicable as it is a systematic review and meta-analysis with no original data from patients.

Statement of Human and Animal Rights/Ethical Approval Not applicable as it is a systematic review and meta-analysis with no original data from patients.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

1. Drewnowski A. The cost of US foods as related to their nutritive value. Am J Clin Nutr. 2010;92(5):1181–8.
2. Mendoza JA, Drewnowski A, Christakis DA. Dietary energy density is associated with obesity and the metabolic syndrome in U.S. adults. Diabetes Care. 2007;30(4):974–9.
3. Cardenas Fuentes G et al. Association of physical activity with body mass index, waist circumference and incidence of obesity in older adults. Eur J Pub Health. 2018;28(5):944–50.
4. Ochs-Balcom HM, Preus L, Nie J, et al. Physical activity modifies genetic susceptibility to obesity in postmenopausal women. Menopause. 2018;25(10):1131–7.
5. Donaldson LF, Bennett L, Baic S, et al. Taste and weight: is there a link? Am J Clin Nutr. 2009;90(3):800S–3S.
6. Drewnowski A. Taste preferences and food intake. Annu Rev Nutr. 1997;17:237–53.
7. Han P, Bagenna B, Fu M. The sweet taste signalling pathways in the oral cavity and the gastrointestinal tract affect human appetite and food intake: a review. Int J Food Sci Nutr. 2018:1–11.
8. Low YQ, Lacy K, Keast R. The role of sweet taste in satiation and satiety. Nutrients. 2014;6(9):3431–50.
9. Aguayo, G.A., et al., Taste preference and psychopathology. Bull Soc Sci Med Grand Duche Luxemb, 2012(2): p. 7–14.
10. Berthoud HR, Zheng H. Modulation of taste responsiveness and food preference by obesity and weight loss. Physiol Behav. 2012;107(4):527–32.
11. Shoar S, Saber AA. Long-term and midterm outcomes of laparoscopic sleeve gastrectomy versus Roux-en-Y gastric bypass: a systematic review and meta-analysis of comparative studies. Surg Obes Relat Dis. 2017;13(2):170–80.
12. Khorgami Z, Shoar S, Andalib A, et al. Trends in utilization of bariatric surgery, 2010-2014: sleeve gastrectomy dominates. Surg Obes Relat Dis. 2017;13(5):774–8.
13. Khorgami Z, Petrosky JA, Andalib A, et al. Fast track bariatric surgery: safety of discharge on the first postoperative day after bariatric surgery. Surg Obes Relat Dis. 2017;13(2):273–80.
14. Ahmed K, Penney N, Darzi A, et al. Taste changes after bariatric surgery: a systematic review. Obes Surg. 2018;28(10):3321–32.
15. *Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0*, ed. J. Higgins and S. Green. 2011: The Cochrane Collaboration.
16. Hutton B, Salanti G, Caldwell DM, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med. 2015;162(11):777–84.
17. Altun H, Hanci D, Altun H, et al. Improved gustatory sensitivity in morbidly obese patients after laparoscopic sleeve gastrectomy. Ann Otol Rhinol Laryngol. 2016;125(7):536–40.
18. Burge JC et al. Changes in patients' taste acuity after Roux-en-Y gastric bypass for clinically severe obesity. J Am Diet Assoc. 1995;95(6):666–70.
19. Ekmekcioglu C, Maedge J, Lam L, et al. Salt taste after bariatric surgery and weight loss in obese persons. PeerJ. 2016;4:e2086.
20. Graham L, Murty G, Bowrey DJ. Taste, smell and appetite change after Roux-en-Y gastric bypass surgery. Obes Surg. 2014;24(9):1463–8.
21. Makaronidis JM, Neilson S, Cheung WH, et al. Reported appetite, taste and smell changes following Roux-en-Y gastric bypass and sleeve gastrectomy: effect of gender, type 2 diabetes and relationship to post-operative weight loss. Appetite. 2016;107:93–105.
22. Nance K, Eagon J, Klein S, et al. Effects of sleeve gastrectomy vs. Roux-en-Y gastric bypass on eating behavior and sweet taste perception in subjects with obesity. Nutrients. 2017;10(1)
23. Pepino MY, Bradley D, Eagon JC, et al. Changes in taste perception and eating behavior after bariatric surgery-induced weight loss in women. Obesity (Silver Spring). 2014;22(5):E13–20.
24. Scruggs DM, Buffington C, Cowan Jr GS. Taste acuity of the morbidly obese before and after gastric bypass surgery. Obes Surg. 1994;4(1):24–8.
25. Tichansky DS, Boughter Jr JD, Madan AK. Taste change after laparoscopic Roux-en-Y gastric bypass and laparoscopic adjustable gastric banding. Surg Obes Relat Dis. 2006;2(4):440–4.
26. Van Vuuren MAJ et al. Taste, enjoyment, and desire of flavors change after sleeve gastrectomy-short term results. Obes Surg. 2017;27(6):1466–73.
27. Wang JL, Yang Q, Hajnal A, et al. A pilot functional MRI study in Roux-en-Y gastric bypass patients to study alteration in taste functions after surgery. Surg Endosc. 2016;30(3):892–8.
28. Zerrweck C, Zurita L, Álvarez G, et al. Taste and olfactory changes following laparoscopic gastric bypass and sleeve gastrectomy. Obes Surg. 2016;26(6):1296–302.
29. Keller KL, Olsen A, Cravener TL, et al. Bitter taste phenotype and body weight predict children's selection of sweet and savory foods at a palatable test-meal. Appetite. 2014;77:113–21.
30. Perna S, Riva A, Nicosanti G, et al. Association of the bitter taste receptor gene TAS2R38 (polymorphism RS713598) with sensory responsiveness, food preferences, biochemical parameters and body-composition markers. A cross-sectional study in Italy. Int J Food Sci Nutr. 2018;69(2):245–52.
31. Oftedal KN, Tepper BJ. Influence of the PROP bitter taste phenotype and eating attitudes on energy intake and weight status in pre-adolescents: a 6-year follow-up study. Physiol Behav. 2013;118:103–11.
32. Andreozzi P, Sarnelli G, Pesce M, et al. The bitter taste receptor agonist quinine reduces calorie intake and increases the postprandial release of cholecystokinin in healthy subjects. J Neurogastroenterol Motil. 2015;21(4):511–9.
33. Disse E, Bussier AL, Veyrat-Durebex C, et al. Peripheral ghrelin enhances sweet taste food consumption and preference, regardless of its caloric content. Physiol Behav. 2010;101(2):277–81.
34. Macedo DM, Diez-Garcia RW. Sweet craving and ghrelin and leptin levels in women during stress. Appetite. 2014;80:264–70.
35. Kalinowski P, Paluszkiewicz R, Wróblewski T, et al. Ghrelin, leptin, and glycemic control after sleeve gastrectomy versus Roux-en-Y gastric bypass-results of a randomized clinical trial. Surg Obes Relat Dis. 2017;13(2):181–8.
36. Fonseca DC, Sala P, Singer J, et al. Upregulation of ghrelin gene expression in the excluded stomach of obese women with type 2 diabetes after Roux-en-Y gastric bypass in the SURMetaGIT study. Obes Surg. 2018;28(3):877–80.
37. Jyotaki M, Sanematsu K, Shigemura N, et al. Leptin suppresses sweet taste responses of enteroendocrine STC-1 cells. Neuroscience. 2016;332:76–87.
38. Cai H, Cong WN, Daimon CM, et al. Altered lipid and salt taste responsivity in ghrelin and GOAT null mice. PLoS One. 2013;8(10):e76553.
39. Zhang Y, Li F, Liu FQ, et al. Elevation of fasting ghrelin in healthy human subjects consuming a high-salt diet: a novel mechanism of obesity? Nutrients. 2016;8(6)
40. Hallersund P, Sjöström L, Olbers T, et al. Gastric bypass surgery is followed by lowered blood pressure and increased diuresis - long term results from the Swedish obese subjects (SOS) study. PLoS One. 2012;7(11):e49696.
41. DeSimone JA, Lyall V. Taste receptors in the gastrointestinal tract III. Salty and sour taste: sensing of sodium and protons by the tongue. Am J Physiol Gastrointest Liver Physiol. 2006;291(6):G1005–10.
42. Simchen U, Koebnick C, Hoyer S, et al. Odour and taste sensitivity is associated with body weight and extent of misreporting of body weight. Eur J Clin Nutr. 2006;60(6):698–705.

43. Monneuse MO, Rigal N, Frelut ML, et al. Taste acuity of obese adolescents and changes in food neophobia and food preferences during a weight reduction session. Appetite. 2008;50(2–3):302–7.
44. Bajerska J, Mildner-Szkudlarz S, Górnaś P, et al. The effects of muffins enriched with sour cherry pomace on acceptability, glycemic response, satiety and energy intake: a randomized crossover trial. J Sci Food Agric. 2016;96(7):2486–93.
45. Chen MC, Wu SV, Reeve Jr JR, et al. Bitter stimuli induce Ca2+ signaling and CCK release in enteroendocrine STC-1 cells: role of L-type voltage-sensitive Ca2+ channels. Am J Physiol Cell Physiol. 2006;291(4):C726–39.
46. Mendieta-Zeron H et al. Biliopancreatic diversion induces villi elongation and cholecystokinin and ghrelin increase. Diabetes Metab Syndr. 2011;5(2):66–70.
47. Sorensen TI et al. Plasma cholecystokinin in obese patients before and after jejunoileal bypass with 3:1 or 1:3 jejunoileal ratio–no role in the increased risk of gallstone formation. Dan Med Bull. 1994;41(4):469–72.
48. Brennan IM, Little TJ, Feltrin KL, et al. Dose-dependent effects of cholecystokinin-8 on antropyloroduodenal motility, gastrointestinal hormones, appetite, and energy intake in healthy men. Am J Physiol Endocrinol Metab. 2008;295(6):E1487–94.
49. Little TJ, Horowitz M, Feinle-Bisset C. Role of cholecystokinin in appetite control and body weight regulation. Obes Rev. 2005;6(4):297–306.