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Changes in Taste Function and Ingestive Behavior Following Bariatric Surgery

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Abstract

Bariatric surgery is the most effective treatment for severe obesity and its related comorbidities. Roux-en-Y Gastric Bypass (RYGB) and Sleeve Gastrectomy (SG) are currently the most popular weight-loss surgeries used worldwide. Following these surgeries, many patients self-report changes in taste perception and decreased preference for unhealthy foods. These reported changes might account for increased adherence to healthier diets and successful weight loss after surgeries. However, researchers have used a variety of methodologies to assess patients' reported changes andresults are discrepant. The goal of this review is to summarize the literature regarding changes to taste function and ingestive behavior following RYGB and SG to examine differences in findings by methodology (indirect vs. direct measurements). We focused our review around changes in sweets, fats, and alcohol because most of the documented changes in ingestive behavior post-surgery are related to changes in these dietary items. We found that studies using surveys and questionnaires generally find that subjects self-report changes in taste and decrease their preference and cravings for energy-dense foods (particularly, sweets and high-fats). However, studies using validated sensory techniques that include oral sampling or by using direct food intake measurements find little to no change in subjects' ability to perceive taste or their preference for energy-dense foods. Therefore, reported changes in taste and food preferences are unlikely to be explained by alterations in taste intensity and diet selection, and are rather related to changes in the rewarding value of food. Further, that RYGB, and likely SG, is associated with increased alcohol consumption and arisk to develop an alcohol use disorder) supports the notion

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K.N. conducted the literature search on the food section and wrote the first draft of the manuscript. M.B.A conducted the literature search on the alcohol section and wrote the first draft for the alcohol section. All authors contributed to writing and editing the manuscript and approved the submitted version.

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that these surgeries alter central circuits of reward that are critical in the regulation of ingestive behavior.

1. Introduction

To date, bariatric surgery is the most successful long-term treatment for severe obesity and its related comorbidities. Patients who receive these types of surgeries can experience a reduction or remission of obesity-related comorbidities such as type 2 diabetes, hypertension, and decreased insulin resistance (Courcoulas, et al., 2018; Jakobsen, et al., 2018), as well as the potential to lose an average of ~60% of their excess body weight (Buchwald, et al., 2009). The most common surgeries currently performed in United States and worldwide are sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB) (Angrisani, et al., 2018). While laparoscopic gastric banding (LAGB) has been a surgical procedure commonly used in the past, this method has been phasing out of popularity (Angrisani, et al., 2018) due to variable, generally smaller weight loss, a higher risk for weight regain, and, therefore, a reduced improvement in glucose control after this surgery when compared to other bariatric procedures like RYGB (Holter, et al., 2017). Thus, LAGB will be briefly mentioned in this review only when used as a direct control group for weight-loss independent effects of RYGB or SG.

RYGB surgery involves creating a small gastric pouch that is attached directly to the jejunum to create the “Roux limb”. The bypassed distal stomach, duodenum, and proximal jejunum are reattached to the distal jejunum to create the common channel. The SG procedure involves removing 2/3 of the stomach along the greater curve, creating a “sleeve-like” structure. Both of these procedures modify the route of ingested nutrients, enabling them to enter the small intestine directly (in RYGB) or faster (in SG). This rerouting of nutrients alters post-ingestive hormones such as peptide YY (PYY), glucagon-like peptide 1 (GLP-1), and others that are involved in the regulation of hunger and satiety and also influence brain regions involved in food and drug reward (De Silva, et al., 2011; Morínigo, et al., 2006). Therefore, it is not surprising that patients who undergo these types of surgeries report changes in their appetite, food preferences, and aspects of flavor perception (Graham, Murty, & Bowrey, 2014; Makaronidis, et al., 2016).

Flavor perception integrates cues from our five senses, but it is mainly driven by taste and retronasal smell, which is when compounds from food activate the olfactory epithelium through the back of the oral cavity (Chaudhari & Roper, 2010). However, people tend to mistakenly use taste as a synonym of flavor, and the intimate entwining of these chemical senses causes people to misappropriate sensations arising from retronasal smell as if they were arising from the taste system (e.g. vanilla “taste”) (Rozin, 1982). In addition, taste function involves different aspects including a sensory-discriminative component (i.e. taste quality and intensity) and a hedonic component (i.e. degree of pleasantness/unpleasantness) (Breslin & Spector, 2008). Therefore, a considerable limitation of studies that examine changes in taste function after undergoing bariatric surgery by using questionnaires is that it is unclear what patients actually mean when they report a change in “taste”. Are they referring to a change in taste or in flavor perception? Additionally, are they referring to changes in perception of stimulus strength, stimulus quality, or hedonic value?

This review will focus mainly on how bariatric surgery may change “taste function” (rather than flavor perception) and ingestive behavior. There are some studies that have examined how bariatric surgery may change orthonasal smell (i.e. smelling through sniffing during inspiration), all finding a similar trend of some form of orthonasal impairment in pre-surgery subjects that was improved after weight loss induced by RYGB (Zerrweck, Gallardo, Calleja, Sepúlveda, & Guilber, 2017), SG (Hancı, et al., 2016; Jurowich, et al., 2014), or both procedures (Holinski, Menenakos, Haber, Olze, & Ordemann, 2015). However, none of the studies found in our search included a direct measure of flavor perception (e.g. mainly the integration of taste with smell) in this population. (Graham, et al., 2014; Hancı, et al., 2016; Holinski, et al., 2015; Jurowich, et al., 2014; Makaronidis, et al., 2016; Zerrweck, et al., 2017; Zerrweck, et al., 2016)In addition, we will focus our review around changes in sweet taste/sweet foods, fat taste/fatty foods, and alcohol because most of the documented changes in taste function or ingestive behavior post-surgery are related to changes in these dietary items.

2. Methods

Articles were searched on PubMed and GoogleScholar and were restricted to peer-reviewed, English language, original research regarding flavor changes and food selection following bariatric surgery. Search terms included “bariatric surgery” OR “metabolic surgery” OR “weight loss surgery” OR “Roux en y gastric bypass” OR “Roux-en-y gastric bypass” OR “sleeve gastrectomy” OR “laparoscopic gastric banding” OR “rygb” OR “sg” OR “lagb” with “smell”, “cravings”, “food preference”, “taste change”, “flavor”, “taste perception”, “alcohol”, or “ethanol”. Articles were scanned by title and abstract and were excluded if they were 1) not relevant to the topic of interest (i.e. eating disorders, depression, etc.) or 2) a review. However, review reference tables were also searched for articles relevant to the topic. Additionally, any article that was relevant to the topic of interest but did not appear in the search or in reference tables was included. Articles published up to July 15, 2019 were considered for inclusion.

3. Results: Changes in Ingestive Behaviors

3.1. Changes in Food Selection via Indirect Measurement

Questionnaires remain the most popular method of evaluating changes in ingestive behavior following bariatric surgery due to their ease of administration and capability of being performed electronically. Early studies in the 1980’s regarding food-related shifts in bariatric populations used the questionnaire method and found that patients significantly decreased their food consumption specifically in the categories of calorically dense high-carbohydrates and fats after RYGB (Coughlin, Bell, Bivins, Wrobel, & Griffen, 1983; Halmi, Mason, Falk, & Stunkard, 1981). Since then, several studies have found decreased (or a trend for decreased) consumption of fats (Bavaresco, et al., 2010; Kruseman, Leimgruber, Zumbach, & Golay, 2010; Laurenius, et al., 2013; Molin Netto, et al., 2017), sweets (Kenler, Brolin, & Cody, 1990), or fats and sweets (Brolin, Robertson, Kenler, & Cody, 1994; Ernst, Thurnheer, Wilms, & Schultes, 2009; Ullrich, Ernst, Wilms, Thurnheer, & Schultes, 2013) following RYGB and SG (Coluzzi, et al., 2016; Sarwer, et al., 2017) in both adults and adolescents.

Interestingly, fat and sweet intake reported by adults who achieve and sustain optimal weight loss following RYGB or SG was similar to that reported by adults who did not achieve and sustain optimal weight loss (Amundsen, Strommen, & Martins, 2017; Chou, et al., 2017; da Silva, Gomes, & de Carvalho, 2016; Furtado, et al., 2018), but those with suboptimal weight loss were less physically active (Amundsen, et al., 2017) or consumed less healthy diets (da Silva, et al., 2016). Moreover, Furtado et al. found that subjects who achieved optimal weight loss reported consuming dessert more frequently than subjects with suboptimal weight loss (Furtado, et al., 2018). However, such a finding may be due to differential underreporting between groups. Findings from some studies suggest that individuals with obesity (Prentice, et al., 1986) and groups with suboptimal weight loss are more likely to underreport fatty food/dessert consumption than individuals without obesity or optimal weight loss (Bingham, et al., 1995; Pryer, Vrijheid, Nichols, Kiggins, & Elliott, 1997).

3.2. Changes in Food Selection via Direct Measurement

In order to simulate a more life-like situation for measuring food selection, a recent pair of studies evaluated ingestive behavior using a novel ad libitum buffet paradigm in which subjects are presented 20 food items and they are allowed to choose their dinner in an all-you-can-eat style. Categories for the food items offered were split into high-fat savory, low-fat savory, high-fat sweet, and low-fat sweet, and analyzed to determine if there were differences in intake after either RYGB or SG surgery. Interestingly, although subjects self-reported an increased preference for low-fat savory options when presented with a picture test before the meal, this preference was not reflected in the foods they chose at the buffet dinner (Nielsen, et al., 2017). Moreover, the only clinically relevant information from the buffet study was that subjects ate significantly less and needed less time to reach satiation and terminate the meal. These results were also replicated in their 2018 follow-up study that examined the same parameters in subjects 18 months post-surgery (Søndergaard Nielsen, et al., 2018), further highlighting the discrepancy between indirect vs. direct measures and the need for more direct measures of food selection.

The studies of Nielsen et al. 2017 and Nielsen et al. 2018 are important because they demonstrate that self-reported changes might not correlate with measured ingestive behaviors, and subjects might not alter food preferences after surgery but simply consume less of what they were eating before. However, every method has its limitations and the buffet paradigm is not an exemption. Firstly, a failure to reflect the preferences displayed during the picture test when evaluated in the buffet setting in the 2017 study may be due to the fact that the pictures used during the self-report test and the items offered at the buffet were not identical. Secondly, experimental conditions that preceded the ad libitum test may have affected its outcome. For example, the pre-loads (liquid meals) served before the buffet meal were mainly sweet, which could have attenuated the ability to detect differences in sweet food preferences before vs. after surgery because subjects could be reducing the amount of sweet food selected even before surgery due to sensory specific satiety (Rolls, Rolls, Rowe, & Sweeney, 1981).

3.3. Changes in Food Cravings via Indirect Measurement

In this review, we use the previously developed terminology of “an intense desire to consume a particular food (or food type) that is difficult to resist” to define food cravings (White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002). Food cravings appear to have profound effects on body weight. For example, individuals who have higher food craving traits display less control over weight loss (Meule, Lutz, Vögele, & Kübler, 2012) and decreases in craving traits are associated with increased weight loss (Batra, et al., 2013). Therefore, it seems important to examine changes in food cravings after bariatric surgery. Patients who seek bariatric surgery crave foods more frequently than healthy controls (Leahey, et al., 2012). Interestingly, the frequency of food cravings and, in particular, the frequency of cravings for sweets and fats is dramatically reduced after bariatric surgery induced weight loss in adult as well as adolescent subjects (Cushing, et al., 2015; Leahey, et al., 2012; Nance, Eagon, Klein, & Pepino, 2017; Pepino, Bradley, et al., 2014; Pepino, Stein, Eagon, & Klein, 2014; Sarwer, et al., 2017). However, the decreased frequency of food cravings might be related to changes in dietary intake and weight loss (Pepino, Bradley, et al., 2014; Sarwer, et al., 2017) and not to surgery-related changes in the gut (at least within the first year post-surgery). For example, weight loss induced by either LAGB or RYGB in adults (Pepino, Bradley, et al., 2014) or by RYGB, SG, or calorie restriction in adolescents (Sarwer, et al., 2017) similarly decreased the frequency of food cravings. Noteworthy, when “intensity” of food cravings rather than frequency of food cravings was used as a construct, a study that followed patients up to 7 years post-surgery showed better improvements in food cravings after RYGB than LAGB (Devlin, et al., 2018).

3.4. Changes in Alcohol Ingestion via Indirect Measurement

In striking contrast to the improvements in food-related ingestive behaviors detailed in the preceding subsections, a growing body of evidence indicates that RYGB and SG (although still very incipient) are associated with an increased risk to develop an alcohol use disorder (AUD) [RYGB: (Conason, et al., 2013; King, et al., 2017; King, et al., 2012; Suzuki, Haimovici, & Chang, 2012; Svensson, et al., 2013), SG: (Ibrahim, et al., 2018)].

Data from several studies suggest that alcohol consumption decreases during the first year post-surgery (Alfonsson, Sundbom, & Ghaderi, 2014; Burgos, et al., 2015; Coluzzi, Iossa, Spinetti, & Silecchia, 2018; Conason, et al., 2013; Svensson, et al., 2013; Woodard, Downey, Hernandez-Boussard, & Morton, 2011). Furthermore, 40–50% of subjects who had a high-risk alcohol use before surgery discontinued high-risk drinking within the first year after RYGB (Ivezaj, et al., 2017; King, et al., 2012; Wee, et al., 2014). However, this pattern of decreased alcohol ingestion is reversed over the second year after surgery (Conason, et al., 2013; Cuellar-Barboza, et al., 2015; King, et al., 2017; King, et al., 2012; Ostlund, et al., 2013; Wee, et al., 2014). Parallel to this increase in alcohol ingestion, there is an increase in the prevalence of AUD over the second year after RYGB but not after LAGB (King, et al., 2017; King, et al., 2012; Ostlund, et al., 2013). A recent prospective study suggests the prevalence of AUD following SG is similar to that after RYGB (Ibrahim, et al., 2018). The few studies that have evaluated participants past the 2-year mark found that the prevalence of AUD continued to increase significantly for many years after RYGB surgery (Backman, Stockeld, Rasmussen, Naslund, & Marsk, 2016; Cuellar-Barboza, et al., 2015; King, et al., 2017; Mitchell, et al., 2015; Svensson, et al., 2013). Remarkably, one in five patients with no history of alcohol problems within one year before surgery reported having symptoms of an AUD within 5 years post-RYGB (King, et al., 2017).

Recent studies provide insight into potential mechanisms that could explain the self-reported or screened increases in alcohol ingestion and the risk to develop an AUD after RYGB. First, the anatomical changes in the gut resulting from RYGB and SG surgical procedures dramatically affect alcohol pharmacokinetics, increasing alcohol absorption and reducing its first pass metabolism (i.e. the fraction of an ingested dose of a drug that is metabolized in its passage through the gut and liver before entering the systemic circulation). Therefore, after RYGB and SG, peak blood alcohol concentration happens faster (within 5–9 minutes after dinking) and peak blood alcohol concentrations are twice as high as those experienced when drinking the same amount of alcohol before surgery (Acevedo, et al., 2018; Klockhoff, Näslund, & Jones, 2002; Pepino, et al., 2015; Steffen, Engel, Pollert, Li, & Mitchell, 2013). The measured changes in alcohol pharmacokinetics are of importance because it is well known that rapid delivery of a psychotropic to the brain can increase its addictive properties (de Wit, Bodker, & Ambre, 1992). RYGB and SG convert alcohol ingestion to the blood profile of an alcohol IV administration, likely increasing the risk for AUD. Second, as mentioned in the introduction, some gut peptides that are involved in food intake are also important for alcohol reward [e.g. PYY (Thiele, Sparta, Hayes, & Fee, 2004), GLP-1 (Davis, et al., 2012), and ghrelin (Davis, et al., 2012; Hajnal, et al., 2012; Jerlhag, et al., 2009; Leggio, et al., 2014)] and can be modified by these surgeries (Madsbad, Dirksen, & Holst, 2014). For example, ghrelin, a well-recognized gut-brain orexigenic peptide, is required for alcohol reward (Jerlhag, et al., 2009). Recent data from animal models of obesity showed that rats that underwent RYGB worked harder than sham-operated controls to obtain alcohol, regardless of whether alcohol was administered orally (Hajnal, et al., 2012; Thanos, et al., 2015) or intravenously (Polston, et al., 2013), and that the increased rewarding value of alcohol after RYGB surgery was, at least in part, mediated by increased sensitivity of brain ghrelin receptors (Hajnal, et al., 2012).

4. Results: Changes in Taste Function

4.1. Indirect Measurements

4.1.1. Sensory-Discriminative Component—Findings from studies that examine changes in taste perception using questionnaires are discrepant. Using a custom made survey titled the Taste Change Survey, subjects reported that sweet taste intensity was increased after undergoing SG (Zerrweck, et al., 2016) but responses were highly variable with both increased (Graham, et al., 2014) and decreased (Tichansky, Boughter, & Madan, 2006) sweet taste sensitivities after undergoing RYGB. Furthermore, using this same questionnaire, subjects post-LAGB reported perceiving sweet taste as more intense than subjects post-RYGB (Tichansky, et al., 2006). However, studies using different self-report questionnaires found that subjects post-SG did not experience changes in sweet taste intensity (Tassinari, et al., 2017).

Subjects reported that fatty foods tasted differently or more intense within one year following RYGB and SG (Van Vuuren, Strodl, White, & Lockie, 2017; Zerrweck, et al., 2016); however, these effects began to diverge based on surgery type when examined more than two years out from surgery; while subjects who underwent RYGB retained these perceived changes (Graham, et al., 2014), those who underwent SG no longer perceived any changes to fat taste (Tassinari, et al., 2017). As there is still severely minimal data on both ingestive behaviors and taste function long term post-surgery, these findings pose a critical point as to why more studies are needed that examine patients beyond the first year post-surgery, as it is entirely possible changes observed within the short term do not last in the long term.

4.1.2. Hedonic Component—Subjects post-RYGB and SG largely report decreased preference and/or liking for sweets (Ammon, et al., 2015; Coluzzi, et al., 2016; Gero, et al., 2017; Zoon, et al., 2018) and fats (Ammon, et al., 2015; Coluzzi, et al., 2016; Faulconbridge, et al., 2016; Gero, et al., 2017; Husted & Ogden, 2014; Thomas & Marcus, 2008; Zoon, et al., 2018). Subjects who underwent SG also reported that they no longer have a desire to consume sweet and fatty foods following their surgeries (Van Vuuren, et al., 2017). It is possible, though, that these changes might wash out after one year post-surgery (Coluzzi, et al., 2016; Kittrell, et al., 2018).

4.2. Direct Measurements

4.2.1. Sensory-Discriminative Component—Typical direct measurements of the sensory-discriminative domain of taste perception include the evaluation of taste quality (i.e. sweet, salty, bitter, sour, umami) and taste sensitivity. Most of the sensory studies in the bariatric population have measured detection thresholds (the minimum concentration a subjects needs to identify a taste stimulus as different from water) or recognition thresholds (the minimum concentration a subject needs to recognize the taste quality of the stimuli) (Bartoshuk, 1978). The literature remains divided on whether or not sweet sensitivity measured at threshold levels is changed after RYGB or SG. Research has indicated both increased sweet taste sensitivity (i.e. decreased sucrose detection and recognition thresholds) (Bueter, et al., 2011; Burge, Schaumburg, Choban, DiSilvestro, & Flancbaum, 1995) or no change in taste sensitivity (Nance, et al., 2017; Pepino, Bradley, et al., 2014; Scruggs, Buffington, & Cowan, 1994) in studies that are relatively comparable in gender distribution and time since surgery. The only difference was in methodology used. It is well established in psychophysics that, in general, changes in a given stimulus concentration do not result in linear changes in its perceived intensity. In particular, taste sensitivity at detection thresholds does not generally correlate with perception of taste intensity of the same taste stimulus at suprathreshold concentrations (which are concentrations more closely related with our food experiences) (Bartoshuk, 1978; Keast & Roper, 2007; Pepino, Finkbeiner, Beauchamp, & Mennella, 2010). Although taste detection thresholds relate fairly well to manipulations of the gustatory system in preclinical models (e.g. see Mathes in this issue), the clinical relevance of surgery-related changes in taste thresholds in people is unclear at this time.

Taste strips can also be used to assess taste sensitivity, and are an alternative measurement to dissolved taste stimuli in water. Strips impregnated with various concentrations of basic taste stimuli (sucrose for sweet, citric acid for sour, sodium chloride for salty, and quinine for bitter) are placed on the tongue and subjects are asked to suck on the strips and correctly identify the taste (Mueller, et al., 2003). Studies both post-RYGB (Holinski, et al., 2015) and post-SG (Altun, et al., 2016) showed overall increased sensitivity to sucrose strips after surgery (i.e. after surgery subjects were able to discriminate more strips correctly). In the study of Altun and collaborators, it is unclear if improvements in taste identification were due to SG-related decreases in body weight or mainly due to learning effects (i.e. becoming more familiar and better at identifying the taste strips with repeated testing) because their study design included a longitudinal a group of people evaluated before and several times after undergoing SG only. However, Holinski et al. found that obese subjects had lower taste strip scores when compared to normal weight controls, and that only those evaluated after RYGB or SG become better at identifying taste strips such that, after surgery, scores were not significantly different from normal weight controls (Holinski, et al., 2015). However, taste strips as a sensory testing method have some limitations. Firstly, as taste stimuli need to be solubilized in order for the taste bud to sense them (Chaudhari & Roper, 2010), changes in saliva content could affect the results of the taste strip scores. Secondly, the correct identification of a taste is still uninformative about changes in perceived intensities.

The few studies that have measured perceived intensity of basic taste stimuli found that taste perception was relatively unchanged following bariatric surgery induced weight loss (Nance, et al., 2017; Pepino, Bradley, et al., 2014). Although the perceived intensity of sucrose was slightly reduced after weight loss induced by RYGB and LAGB, there was no association between these surgeries and changes to the perceived intensity of the sweetness of glucose, saltiness of NaCl, or savoriness of monosodium glutamate (MSG, the prototypical stimuli for umami taste) (Pepino, Bradley, et al., 2014). Additionally, there were no changes to perceived intensity of sucrose, glucose, NaCl, or MSG within the first year after RYGB or SG (Nance, et al., 2017). These findings suggest that reported changes in sweet intake after surgery are unlikely to be explained by changes in perceived intensity of sweetness.

4.2.2. Hedonic Component—Using forced-choice preference tests, studies found decreased (or a trend for decreased) sucrose preferences following weight loss induced by RYGB, SG, and LAGB (Nance, et al., 2017; Pepino, Bradley, et al., 2014). Additionally, recent studies suggest that SG also imparts beneficial shifts to sweet liking that LAGB does not. Using a 10-sample habituation paradigm to 24% w/v sucrose, pre-bariatric subjects rated the samples as mainly pleasant. However, after receiving RYGB or SG, subjects found the 24% sucrose mainly unpleasant (Nance, et al., 2017). The observation that subjects post-LAGB still found the samples as pleasant as they did before surgery (Pepino, Bradley, et al., 2014) suggests that changes in the hedonic value of sweetness are not explained solely by decreased body weight or diet-related changes. Convergent with these findings of a shift in the hedonic value of sweetness after weight loss induced by either RYGB or SG, it has been shown that, following RYGB in adults (Miras, et al., 2012) and SG in adolescents (Abdeen, Miras, Alqahtani, & le Roux, 2019), patients reduced their willingness to work for a sweet candy reward (a measure of “wanting”) in a progressive ratio paradigm. It is possible that these shifts in the hedonic value of sweetness are due to nutritional counseling received by patients both before and after surgery. However, the fact that patients from different surgical procedures all receive similar nutritional counseling, but only RYGB and SG (and not

LAGB) show a decrease in the hedonic value of sweetness suggest that such a possibility is unlikely

5. Applied Implications and Future Directions

The major implication of this review is that studies using direct vs. indirect measures to assess taste function and ingestive behavior following bariatric surgery are severely discrepant. This is likely due to the fact that peripheral taste function is not altered by the surgeries or by surgery-induced weight loss, and that other mechanisms are governing these reported changes. One popular hypothesis is that these surgeries instead alter central processes of reward, which could then lead to altered hedonic responses to food. Researchers have demonstrated higher opioid receptor availability (Karlsson, et al., 2016), decreased brain reward activation to high-calorie food pictures (Scholtz, et al., 2014), and altered dopamine D2R receptor availability (Dunn, et al., 2010; Steele, et al., 2010) after RYGB and/or SG. If patients are now experiencing a significantly altered reward sensation when eating the same type of food as they were eating before surgery, it is possible that, through post-ingestive feedback, they mistake the altered reward as though food now tastes off (e.g. “sweeter” or “fattier”). Following this notion, it is possible that the same mechanisms purported to explain the increase in AUD following surgery (i.e. rapid absorption processes and altered gut peptides) are also responsible for reported “taste” changes. As discussed in subsection 3.4, the alteration of gut anatomy after RYGB or SG causes a near instantaneous and much increased peak blood alcohol concentration. Similar to the rapid delivery of alcohol after RYGB/SG, the ingestion of a meal after these procedures results in a rapid delivery of glucose to the systemic circulation, which triggers a faster and bigger spike in blood insulin and other hormones (Bradley, et al., 2012; Bradley, et al., 2014) that affect food reward. Therefore, it is possible that these profound changes in the metabolic responses to a meal following RYGB/SG heighten sensory specific satiety and rapidly shift patients’ hedonic responses to food stimulus.

It is imperative that the mechanisms underlying the effectiveness (as well as mechanisms that lead to the detriments) of bariatric procedures are elucidated as they could provide important clinical implications for successful weight loss and quality of life following surgery. Specifically, once the specific mechanism as to why surgeries like RYGB and SG are as effective as they are is discovered, it would be of importance for studies to examine the mechanism long-term from surgery and how this might correlate to successful vs. unsuccessful weight loss, diet choice, eating behaviors, and more. Therefore, once both the mechanism and how it functions over time are more fully studied, clinicians could use this information to educate patients on how their surgery is going to confer weight loss and remission of comorbidities, and what they must do on their part in order to ensure maximal aid over time. On the other hand, it is also important for mechanisms and warning signs for the detriments of the surgeries, like increased risk of developing an AUD, are made clear as well. Therefore, if studies could determine criteria that could categorize individuals as high-risk even before receiving surgeries, clinicians could possibly have a better grasp on educational material for those receiving the surgery and even criteria for who would or would not make a good candidate for different bariatric procedures.

Future study designs should focus on including long-term measures as data long-term post-surgery is severely lacking in the current literature. Studies should also focus on examining potential changes in flavor perception (i.e. integrate measures of taste with retronasal and orthonasal smell), as it is widely agreed upon that changes in peripheral taste alone are likely not the mechanism for subjects' reported "taste" changes. Additionally, it would be interesting to see more sensory studies integrate changes in gut anatomy and gut hormones (Karamanakos, Vagenas, Kalfarentzos, & Alexandrides, 2008; Korner, et al., 2009; le Roux, et al., 2006; Lee, et al., 2011; Peterli, et al., 2009) with documented changes in brain reward (Dunn, et al., 2010; Karlsson, et al., 2016; Scholtz, et al., 2014; Steele, et al., 2010) in future studies.

6. Conclusions

Questionnaire data indicates distinct self-reported changes in taste associated with decreased consumption of sweets and fats following bariatric surgery. However, these reported "taste" changes are not evident when carefully examined by validated sensory methods and real-life emulation studies. When taken together, these studies suggest that the taste changes perceived after bariatric surgery lie outside the realm of peripheral taste function and more within the realm of changes in central processes in taste that involve the hedonic and rewarding value of food, which can impact food consumption. That RYGB, and likely SG, are associated with an increased risk to develop an AUD further supports the notion that these surgeries alter central circuits of reward that are critical in the regulation of ingestive behavior.

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Table 1:

Fat and Sweet Intake using Questionnaires

CATEGORY	STUDY	POPULATION	SURGERY TYPE	TIME SINCE SURGERY	METHOD	FINDINGS
Fats	Amundsen et al., 2017	42 female 7 male	RYGB	>1 YR (WEIGHT REGAIN VS WEIGHT LOSS)	Food Frequency Questionnaire	No difference in fat intake between suboptimal vs acceptable weight loss
Fats	Bavaresco et al., 2010	41 female 7 male	RYGB	PRE, 1, 3, 6, 8, 12 MO	24 hour dietary recall + NUTWIN-UNIFESP software	↓ fat intake at all times tested
Fats	Brolin et al., 1994	117 female 21 male	RYGB, Vertical Banded Gastroplasty	PRE, 6, 12, 18, 24, 36 MO	Verbal report intake + nutrition modeling software	↓ fat intake at 6 & 36 MO
Fats	Chou et al., 2017	30 female 10 male	SG	5 YR	Food Frequency Questionnaire	No relationship between fat intake and weight loss
Fats	Coluzzi et al., 2016	22 female 8 male	SG	PRE, 6, 12, 24 MO	Modified Suter Questionnaire	↓ interest in fats at 6, 12, and 24 MO
Fats	Coughlin et al., 1983	21 female 4 male	RYGB	PRE, 1, 3, 6, 12 MO	Dietary recall & checklist	↓ fat intake before reaching a plateau at 6 MO
Fats	Da Silva et al., 2016	71 female 9 male (61 weight stable vs. 19 weight regain)	RYGB	42 MO	Healthy Eating Index	No difference of fat intake between weight regain vs. weight stable subjects
Fats	Furtado et al., 2018	88 female 17 male (64 success vs. 41 failure)	RYGB	48–56 MO	24 hour dietary recall + Avanutri software	No difference in fat intake between weight loss failure vs. success groups
Fats	Halmi et al., 1981	70 female 10 male	RYGB	PRE, 6, 12, 24 MO	Structured interview	↓ fat intake
Fats	Kenler et al., 1990	81 female 23 male	RYGB, Horizontal Gastroplasty	PRE, 6 MO INTERVALS UP TO 24 MO	Verbal report intake + nutrition modeling software	↔ fat intake
Fats	Kruseman et al., 2010	80 female 0 male	RYGB	PRE, 8 YR	4 day dietary intake record	↓ fat intake (trend)
Fats	Laurenius et al., 2013	31 female 12 male	RYGB	PRE, 6 W, 6 MO, 2 YR	Swedish Obese Subjects Questionnaire	↓ fat intake at all times fisted
Fats	Molin Netto et al., 2017	39 female 2 male	RYGB	PRE, 6 MO	Food Frequency Questionnaire	↓ fat intake
Fats	Sarwer et al., 2017	219 female 69 male (adolescent)	RYGB, SG	PRE, 6, 12, 24 MO	Minnesota Nutrition Data System	↓ fat intake

CATEGORY	STUDY	POPULATION	SURGERY TYPE	TIME SINCE SURGERY	METHOD	FINDINGS
Sweets	Amundsen et al., 2017	42 female 7 male	RYGB	>1 YR (WEIGHT REGAIN VS WEIGHT LOSS)	Food Frequency Questionnaire	No difference added sugar intake between suboptimal vs. acceptable weight loss
Sweets	Brolin et al., 1994	117 female 21 male	RYGB, Vertical Banded Gastroplasty	PRE, 6, 12, 18, 24, 36 MO	Verbal report intake + nutrition modeling software	↓ sweet intake at 6, 12, 18, & 24 MO
Sweets	Coluzzi et al., 2016	22 female 8 male	SG	PRE, 6, 12, 24 MO	Modified Suter Questionnaire	↓ interest in sweets at 6, 12, and 24 MO
Sweets	Da Silva et al., 2016	71 female 9 male (61 weight stable vs. 19 weight regain)	RYGB	42 MO	Healthy Eating Index	No difference of sweet intake between weight regain vs. weight stable subjects
Sweets	Ernst et al., 2009	165 female 46 male	RYGB, LAGB	>/= 1 YR	Food Frequency Questionnaire	↓ consumption of fatty sweets (desserts) post-RYGB
Sweets	Furtado et al., 2018	88 female 17 male (64 success vs. 41 failure)	RYGB	48–56 MO	24 hour dietary recall + Avanutri software	↑ dessert intake in weight loss success group
Sweets	Kenler et al., 1990	81 female 23 male	RYGB, Horizontal Gastroplasty	PRE, 6 MO INTERVALS UP TO 24 MO	Verbal report intake + nutrition modeling software	↓ decreased sweet intake
Sweets	Ullrich et al., 2013	44 patients	RYGB	PRE, ~16 MO	Power of Food Scale, Food Frequency Questionnaire	↓ consumption fatty sweets (desserts)

Table 2:

Fat and Sweet Cravings using Questionnaires

CATEGORY	STUDY	POPULATION	SURGERY TYPE	TIME SINCE SURGERY	METHOD	FINDINGS
Fats & Sweets	Cushing et al., 2015	10 female 6 male (adolescents)	RYGB	PRE, 3, 6, 12, 18, 24 MO	Food Craving Inventory	↓ sweet cravings ↓ fast food fat cravings ↓ high-fat cravings
n/a	Devlin et al., 2018	156 female 28 male	RYGB, LAGB	PRE, 1, 2, 3, 4, 5, 6, 7 YR	Custom questions	↓ Intensity of cravings after RYGB
Fats & Sweets	Leahey et al., 2012	46 female 6 male	RYGB, LAGB	PRE, 3, 6 MO	Food Craving Inventory	↓ sweet cravings ↓ fast-food fats cravings ↔ high fats cravings
Fats & Sweets	Nance et al., 2017	27 female 8 male	RYGB, SG	PRE, <1 YR	Food Craving Inventory	↓ sweet cravings ↓ fast food fat cravings ↓ high-fat cravings
Fats & Sweets	Pepino et al., 2014	27 female 0 male	RYGB, LAGB	PRE, <1 YR	Food Craving Inventory	↓ sweet cravings ↓ fast-food fats cravings ↔ high fats cravings
Fats & Sweets	Pepino et al., 2014	39 female 6 male	RYGB, LAGB, SG	PRE, <1 YR	Food Craving Inventory	↓ sweet cravings ↓ fast food fat cravings ↓ high-fat cravings
Fats & Sweets	Sarwer et al., 2017	219 female 69 male (adolescent)	Bariatric surgery (RYGB/SG) vs. lifestyle modification	PRE, 6, 12, 24 MO	Food Craving Inventory	↓ sweet cravings ↓ fast food fat cravings ↓ high-fat cravings

Table 3:

Fat and Sweet Taste Function using Questionnaires

CATEGORY	STUDY	POPULATION	SURGERY TYPE	TIME SINCE SURGERY	METHOD	FINDINGS
Sensory Discriminatory	Graham et al., 2014	89 female 14 male	RYGB	25 MO	Taste Change Survey	↑ sugary taste of sweets foods
Sensory Discriminatory	Tassinari et al., 2017	37 female 13 male	SG	PRE, >24 MO	EPIC Food Frequency Questionnaire	↔ sweet or fat taste intensity
Sensory Discriminatory	Tichansky et al., 2006	110 patients	RYGB, LAGB	> 1 MO	Taste Change Survey	↓ sweet taste sensitivity
Sensory Discriminatory	Van Vuuren et al., 2017	86 female 20 male	SG	4–6 W, 6–8 MO	Taste Desire and Enjoyment Change Questionnaire	↑ sweet and fat taste sensitivity
Sensory Discriminatory	Zerrweck et al., 2016	119 female 64 male	RYGB, SG	10 MO	Taste Change Survey	Change of taste in fatty foods ↑ sweet taste sensitivity
Hedonics	Ammon et al., 2015	14 female 1 male	SG	PRE, 6 W	Food Preference Questionnaire	↓ hedonic ratings for sweet and fatty foods ↓ preference for fats
Hedonics	Coluzzi et al., 2016	22 female 8 male	SG	PRE, 6, 12, 24 MO	Modified Suter Questionnaire	↓ preference for sweets that might wash out over time ↓ preference for fats
Hedonics	Faulconbridge et al., 2016	59 female 0 male	RYGB, SG	PRE, 6 MO	Food Images Test	↓ liking for high-fat foods
Hedonics	Gero et al, 2017	77 female 23 men	SG	PRE, 6 D, 6 MO	Visual Analogue Scale Questionnaire	↓ sweet and fat preferences at both post-surgery time points
Hedonics	Husted et al., 2014	83 female 8 male	RYGB, LAGB, Duodenal Switch, Other	PRE, 3 MO	Written and visual food-type preferences	↓ liking for high-fat foods
Hedonics	Kittrell et al., 2018	155 female 27 male	RYGB	<12 MO, >12 MO	Self-Assessment Manikin	↓ sweet and fat preferences within 1 year that may attenuate further out from surgery
Hedonics	Thomas et al., 2008	29 female 9 male	RYGB	3–29 MO	Food Frequency Questionnaire	↓ fat preferences
Hedonics	Van Vuuren et al.,2017	86 female 20 male	SG	4–6 W, 6–8 MO	Taste Desire and Enjoyment Change Questionnaire	↓ desire to consume sweet and fatty foods
Hedonics	Zoon et al., 2018	15 female 4 male	RYGB	PRE, 2 MO	Macronutrient and Taste Preference Ranking Test	↓ sweet and fat preferences

Table 4:

Fat and Sweet Taste Perception using Sensory Methods

CATEGORY	STUDY	POPULATION	SURGERY TYPE	TIME SINCE SURGERY	METHOD	FINDINGS
Sensory Discriminatory	Altun et al., 2018	30 female 22 male	SG	PRE, 1 MO, 3 MO	Taste Strips	↑ sweet taste sensitivity
Sensory Discriminatory	Bueter et al., 2011	15 female 3 male	RYGB	PRE, 2 MO	Sucrose Detection Thresholds	↑ sweet taste sensitivity
Sensory Discriminatory	Burge et al., 1995	8 women 6 men	RYGB	PRE, 6 W, 12 W	Recognition Thresholds	↑ sweet taste sensitivity
Sensory Discriminatory	Holinski et al., 2015	44 female 23 male	RYGB, SG, LAGB	PRE, 2 W, 3 MO, 6 MO	Taste Strips	↑ sweet taste sensitivity
Sensory Discriminatory	Nance et al., 2017	27 female 8 male	RYGB, SG	PRE, <1 YR	Detection Thresholds, Suprathreshold Intensities	↔ in sucrose detection thresholds ↔ in sucrose suprathreshold intensities ↔ in glucose suprathreshold intensities
Sensory Discriminatory	Pepino et al., 2014	27 female 0 male	RYGB, LAGB	PRE, <1 YR	Detection Thresholds, Suprathreshold Intensities	↔ in sucrose detection thresholds ↓ sucrose suprathreshold intensities ↔ glucose suprathreshold intensities
Sensory Discriminatory	Scruggs et al., 1994	16 female 0 male	RYGB	PRE, 30, 60, 90 D	Detection and Recognition Thresholds	↔ in sucrose detection or recognition thresholds
Hedonics	Abdeen et al. 2019	16 patients (adolescent)	SG	PRE, 12 W, 52 W	Progressive Ratio Task	↓ “wanting” of a sweet/fat candy reward
Hedonics	Miras et al., 2012	12 female 9 male	RYGB	PRE, 8 W	Progressive Ratio Task	↓ “wanting” of a sweet/fat candy reward
Hedonics	Nance et al., 2017	27 female 8 male	RYGB, SG	PRE, <1 YR	Sucrose Preferences, Sucrose Habituation	↓ sucrose preferences (trend) ↓ sucrose liking
Hedonics	Pepino et al., 2014	27 female 0 male	RYGB, LAGB	PRE, <1 YR	Sucrose Preferences, Sucrose Habituation	↓ sucrose preferences ↓ sucrose liking only in RYGB