On oral health before and after obesity treatment

Studies on clinical and patient-reported outcomes

Negin Taghat

Department of Behavioral and Community Dentistry

Institute of Odontology

Sahlgrenska Academy, University of Gothenburg

UNIVERSITY OF GOTHENBURG

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negin.taghat@gu.se
negin.taghat@vgregion.se

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As you start to walk on the way, the way appears

-Rumi

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Negin Taghat

Department of Behavioral and Community Dentistry, Institute of Odontology
Sahlgrenska Academy, University of Gothenburg
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ABSTRACT

The overall aim of this thesis was to study the oral health of individuals with obesity and how oral health may be affected by medical and surgical obesity treatment. The thesis comprises three study populations, with Paper I and IV studying female participants, while Paper II and III includes both genders. Paper I is a cross-sectional study of obese women (Body Mass Index, BMI ≥ 35 kg/m^2, n = 118), with the aim to describe oral health with increasing degrees of obesity and associations between obesity and dental caries. Paper II is a case series designed to describe the oral health profile of bariatric individuals (n = 14). Paper III is a questionnaire study aimed to examine how individuals (n = 1182) treated with gastric bypass perceived their oral health and oral health related quality of life (OHRQoL). Paper IV is a longitudinal follow-up study of the Paper I population aimed to compare the effect of bariatric surgery with medical obesity treatment on dental caries estimates until two years after the intervention. The results demonstrated that obese women had poor oral health habits and that there was an association between increasing degrees of obesity and dental caries frequency. The associations were robust, also after adjusting for confounders (Paper I). After bariatric surgery, both women and men may struggle with oral health problems with high frequencies of dental caries and hyposalivation (Paper II). In Paper III, a high proportion of women and men who underwent bariatric treatment reported poor self-perceived oral health and impacts on their OHRQoL. A longitudinal follow-up showed a higher frequency of caries lesions in women two years after surgical obesity treatment but not after medical treatment. The positive associations between surgical obesity treatment and dental caries were robust also after adjustments for confounders (Paper IV). In conclusion, the findings in this thesis indicate poor oral health and higher caries frequency with increasing BMI (Body Mass Index) in obese women, and oral health problems were observed in both men and women following bariatric surgery with impacts on OHRQoL. The findings can serve as a basis for adapting preventive dental care for obese and bariatric patients.

Keywords: bariatric surgery, dental caries, obesity, obesity management, oral health

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SAMMANFATTNING PÅ SVENSKA

Obesitas (Body Mass Index, BMI ≥ 30 kg/m^2), på svenska fetma, är idag ett globalt hälsoproblem. Det är en riskfaktor för utvecklingen av olika sjukdomar så som hjärt-kärlsjukdomar och diabetes. Behandling av obesitas kan delas in i två huvudgrupper; medicinsk behandling respektive kirurgisk behandling. Den medicinska behandlingen inkluderar kostförändringar och fysisk aktivitet samt ibland även tillägg av specifika läkemedel. I Sverige genomfördes ca 5000 obesitasoperationer 2022. Både den medicinska och den kirurgiska behandlingen kan leda till en rad kort- och långsiktiga komplikationer. Det saknas idag kunskap om hur obesitas och obesitasbehandling påverkar den orala hälsan.

Avhandlingens övergripande syfte är att undersöka den orala hälsan hos obesa individer och hur den påverkas av kirurgisk respektive medicinsk obesitas-behandling. Studie I är en tvärsnittsstudie med syfte att undersöka den orala hälsan hos individer (n = 118) med ökande grad av obesitas samt samband mellan obesitas och karies. Studie II är en fallserie som beskriver oralt status och oral hälsorelaterad livskvalitet hos individer (n = 14) som genomgått kirurgisk obesitasbehandling. Studie III är en tvärsnittsstudie som undersöker självupplevd oral hälsa och påverkan på den orala hälsorelaterade livskvaliteten hos kirurgiskt behandlade individer (n = 1182). Studie IV är en longitudinell studie med målsättning att jämföra effekten av medicinsk respektive kirurgisk behandling på kariesfrekvensen från före till två år efter obesitasbehandling.

Resultaten visade att många obesa individer hade dåliga orala hälsobeteenden och att det fanns associationer mellan ökande obesitasgrad och karies (Studie I). Efter kirurgisk obesitasbehandling kan individer få problem med sin orala hälsa, både objektivt med exempelvis karies och nedsatt salivsekretion och subjektivt (Studie II). I Studie III uppvisade en hög andel av de som genomgått kirurgisk behandling dålig självupplevd oral hälsa och påverkan på sin orala hälsorelaterade livskvalitet. Den longitudinella uppföljningen (Studie IV) visade på högre frekvens av karies två år efter genomförd behandling på individer som genomgick kirurgisk intervention, men inte individer som genomgick medicinsk behandling. Associationerna mellan karies och obesitasbehandling var signifikanta även efter justering för påverkande faktorer.

Sammanfattningsvis visade resultaten i denna avhandling att obesa individer löper risk för dålig oral hälsa med stigande BMI-nivåer. Individer som genomgått kirurgisk obesitasbehandling kan ha både objektiv och subjektiv påverkan på den orala hälsan och sin orala hälsorelaterade livskvalitet. Resultatet kan tjäna som underlag för att skapa förutsättningar för preventiv tandvård för dessa grupper.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Taghat N, Lingström P, Mossberg K, Fändriks L, Eliasson B, Östberg AL. Oral health by obesity classification in young obese women - a cross-sectional study. Acta Odontol Scand. 2022;80:596-604.

II. Taghat N, Mossberg K, Lingström P, Björkman S, Lehrkinder A, Werling M, Östberg AL. Oral health profile of postbariatric surgery individuals: A case series. Clin Exp Dent Res. 2021;7:811–18.

III. Taghat N, Werling M, Östberg AL. Oral health-related quality of life after gastric bypass surgery. Obes Surg. 2020;30:224–32.

IV. Taghat N, Mossberg K, Lingström P, Petzold M, Östberg AL. Impact of medical and surgical obesity treatment on dental caries: A two-year prospective cohort study. Accepted for publication in Caries Res. August 2023.

CONTENT

ABBREVIATIONS

AGB	Adjustable Gastric Banding
BASUN	BAriatric Surgery SUbstitution and Nutrition study
BDDS	Biliopancreatic Diversion with Duodenal Switch
BMI	Body Mass Index
BoP	Bleeding on Probing
CFU	Colony Forming Unit
CI	Confidence Interval
CPI	Community Periodontal Index
DMFT	Decayed Missing Filled Teeth
FDI	Federation Dentaire Internationale = World Dental Federation
GBP	Gastric Bypass
GCF	Gingival Crevicular Fluid
ICDAS	International Caries Detection and Assessment System
kg	kilogram
kcal	kilocalories
LED	Low Energy Diet
m	meters
MT	Medical Treatment
NBHW	National Board of Health and Welfare
OHIP	Oral Health Impact Profile
OHRQoL	Oral Health Related Quality of Life
PPD	Probing Pocket Depth

QoL	Quality of Life
RYGB	Roux-en-Y Gastric Bypass
SD	Standard Deviation
SG	Sleeve Gastrectomy
SM	Streptoccocus Mutans
SKaPa	Svenskt Kvalitetsregister för Karies och Parodontit = The Swedish Quality Registry for Caries and Periodontal disease
SOReg	Scandinavian Obesity Surgery Registry
SSB	Sugar Sweetened Beverages
SWS	Stimulated Whole Saliva
UWS	Unstimulated Whole Saliva
VLED	Very Low Energy Diet
WHO	World Health Organization

PREAMBLE

Obesity has become a global health concern and an increasing number of people are now considered obese or overweight worldwide. Obesity can affect health and overall quality of life; hence, different treatment methods have been developed over the years to reduce body weight. In recent decades there has been a rise in bariatric surgery as a weight loss intervention method for those with morbid obesity. While studies have sought to shed light upon the mechanisms of obesity, bariatric surgery and its implications and consequences on overall health and wellbeing, its impact on oral health has largely been overlooked. Medical professionals often fail to consider oral health, although it is an essential component for overall wellbeing throughout a person's lifespan. A person's ability to smile, eat and chew without pain or oral disease is crucial for their wellbeing and the loss of these abilities for different reasons can be detrimental to both health and quality of life.

During my years as a dental clinician, I have come across both patients with obesity, and patients who have undergone bariatric surgery with varying degrees of oral problems. Some are open about the bariatric procedures they have undergone while others have been less forthcoming. The topics at hand are often sensitive in nature and may cause uneasiness in both the dental clinician and the patient. Does anything change in the oral cavity with obesity, obesity treatment or is it our perception and prejudice that something must have changed? With these thoughts in mind, I applied to a research course, never fully anticipating where it might take me. The culmination of my work is now presented in this thesis. My hope is that it may contribute to our understanding of the impact of obesity and obesity treatment on oral health so that we are better equipped to help our patients in the future.

1 INTRODUCTION

1.1 ORAL HEALTH AND DISEASES

Historically, health in the field of medicine and dentistry has had a strong biomedical perspective i.e., health has been viewed in terms of the presence or absence of disease (Brondani & MacEntee, 2014). Although the World Health Organization (WHO) adopted a more holistic approach in 1946 by defining health as a *"complete physical, mental, and social well-being and not merely the absence of disease or infirmity"* (WHO, 2020) the biomedical perspective has continued to dominate in both health and oral health research (Brondani & MacEntee, 2014).

Within dentistry, the World Dental Federation (FDI) introduced the following definition of oral health in 2016 to be applied in both clinical practice and within dental, oral and craniofacial research: *"Oral health is multifaceted and includes the ability to speak, smile, smell, taste, touch, chew, swallow, and convey a range of emotions through facial expressions with confidence and without pain, discomfort, and disease of the craniofacial complex"* (Glick et al., 2016). This definition was suggested together with a framework to consider the complexity of oral health, and to establish that the absence of oral disease does not constitute oral health by itself. The framework comprises three core elements of oral health: disease and condition status, physiological function, and psychosocial function. The core elements in turn, may be influenced by driving determinants and moderating factors. Driving determinants constitute factors that can influence oral health i.e., environmental and biological factors, health behaviors and healthcare access. Moderating factors are factors that influence how a person rates their own oral health i.e., sociodemographic and cultural factors as well as beliefs and coping strategies (Glick et al., 2016).

Although it has been established that oral disease does not cover the whole spectrum of oral health, it is an important element. Oral disease and oral conditions affect the mouth, gums, teeth, and oral mucosa. Globally, oral disease affects 3.5 billion people, with dental caries being the most frequently reported condition. Other common oral diseases include periodontal disease, tooth loss and oral cancers (WHO, 2023).

1.1.1 DENTAL CARIES – EPIDEMIOLOGY

According to a large overview of epidemiological studies, untreated caries was present globally in 2.0 billion adults and 0.5 billion children with deciduous teeth in 2019 (Wen et al., 2022). The caries prevalence varies greatly across populations with the prevalence of untreated caries being highest in lower-middle and higher-middle income countries and lowest in high income countries (GBD 2017 Oral Disorders Collaborators et al., 2017; Wen et al., 2022). Worldwide caries estimates are, however, uncertain due to challenges of high-quality data collection in many low- income countries (Wen et al., 2022).

In Europe, there has been a reduction over time in caries prevalence across many populations in both adults and adolescents, but there are large regional differences (Carvalho & Schiffner, 2019; Skeie et al., 2022). In one study, the number of Decayed Missing Filled Teeth (DMFT) ranged from 6.6 to 17.6 among adults aged 35-45 years in Europe (Carvalho & Schiffner, 2019). In Sweden, repeated cross-sectional studies in the county of Jönköping have shown a steady decrease in the prevalence of dental caries since the 1970s in both children and adults (Norderyd et al., 2015). This has been attributed to the introduction of fluoride use and preventive dental programs within the Swedish public dental health service (Hugoson & Koch, 1981). Epidemiological data on oral health in Swedish adults is scarce and available reports are mostly on children and adolescents. Data presented by the Swedish National Board of Health and Welfare (NBHW) in 2021 showed that 36% of young adults (23-year-olds) were without manifest lesions i.e., caries lesions in need of restorative dental treatment (Socialstyrelsen, 2021). There are, however, regional differences in caries prevalence which could be observed in data presented by The Swedish Quality Registry for caries and periodontal disease (SKaPa), a national registry for dental health. For example, the number of decayed and/or filled surfaces for 20-29-year-olds ranged from 3.2-5.9 and for 30-39-year-olds from 5.4-9.7 in different Swedish counties (SKaPa, 2022). Overall, the number of decayed and/or missing teeth has decreased in the adult population, especially for those aged 30-69 years. However, there is an increase in caries prevalence in older age groups ($\geq$ 70 years) (SKaPa, 2022).

It should be noted that data from both the NBHW and SKaPa do not account for enamel caries and hence the true prevalence of the caries disease in their reports is most probably underestimated. The prevalence of dental caries is higher when enamel caries is taken into account (Skeie et al., 2022; André Kramer et al., 2014).

1.1.2 DENTAL CARIES – ETIOLOGY

Dental caries occurs as the hard tissues of the tooth, the enamel and dentin, break down due to demineralization. The demineralization is a result of an imbalance in the ecological composition of the dental biofilm, as suggested by the "ecological plaque hypothesis" (Marsh et al., 2015). When pH levels fall below the critical point, pH 5.5 for enamel, demineralization takes place (Bardow & Vissink, 2015). Intake of fermentable carbohydrates is the main reason for lowered pH levels in the biofilm as carbohydrates provide a substrate for acidogenic bacteria. Prolonged exposure to a carbohydrate-rich diet will cause a shift towards an environment favoring aciduric and acidogenic bacteria, resulting in increased risk for tooth mineral loss (Tanzer et al., 2001; Marsh et al., 2015).

The Streptococcus Mutans (SM), Streptoccocus Sobrinus and Lactobacillus bacteria are considered important for caries initiation and progression (Tanzer et al., 2001). Specific subtypes of SM have also been shown to have more cariogenic properties than other strains (Esberg et al., 2017). However, a large number of other bacteria such as for example non-mutans streptococci, Actinomyces and Bifidobacterium may contribute and play a role in the caries process (Takahashi & Nyvad, 2011).

1.1.3 DENTAL CARIES – RISK MODIFIERS

The presence of specific bacteria together with a carbohydrate-rich diet does not *per se* result in caries. The disease is multifactorial with an array of components that can shift the balance to one favoring remineralization or demineralization (Selwitz et al. 2007). Dietary habits are considered a risk factor for caries development (Chapple et al., 2017). Consumption of easily fermentable carbohydrates, intake frequency and snacking behavior all contribute to the disease risk (Bernabé et al., 2016; Moores et al., 2022). By following the current guidelines to limit the amount of free sugar in the diet to less than 10%, in line with WHO recommendations, a reduction in caries can be achieved (Moores et al., 2022).

Aside from dietary changes, fluoridated toothpaste is considered the most important preventive measure against dental caries (Walsh et al., 2019). The use of fluoridated toothpaste reduces the caries increment in both children and adults when compared to non-fluoridated toothpaste (Walsh et al., 2019). Using of other fluoridated products has also shown caries-inhibiting effects (Marinho et al., 2016). Habits related to dietary intake and fluoride usage thus affect the caries risk, but biological and physiological factors such as genetic components and salivary properties also influence the susceptibility to caries (Chapple et al., 2017).

Human saliva with its flow and composition is the first defense against oral diseases. The salivary flow aids with oral sugar dilution and oral clearance. Meanwhile, the salivary composition of different proteins, agglutinins and immunoglobulins has antimicrobial, and protective qualities that reduce the biofilm's vulnerability to attaching bacteria. The salivary components, including phosphate, bicarbonate and calcium, aid with buffering capacity and in the remineralization process (Bardow & Vissink, 2015). Hence, the inherent salivary properties within individuals and changes to the salivary flow rate or composition can increase the caries risk (Närhi et al., 1992; Bardow & Vissink, 2015). Subnormal salivary flow levels or changes in the salivary composition can occur due to medication, age, several systemic and genetic diseases, and radiotherapy (Närhi et al., 1992; Twetman et al., 2002; Klingberg et al., 2007; Bardow & Vissink, 2015; Sabharwal et al., 2021). Cognitive and functional impairment due to medical conditions, for example, dementia, as well as increased polypharmacy in an aging population may also impact both disease initiation and progression (Närhi et al., 1992; Chen et al., 2015).

1.1.4 DENTAL CARIES – MEASURES

To be able to measure dental caries in both clinical and epidemiological contexts, several caries detection systems are available. Visual-tactile detection methods are widely used to detect and diagnose caries with varying content validity (Ismail 2004). The most widely used method to report caries experience is the Decayed, Missing, Filled, Teeth (DMFT) system introduced in the late 1930s (Klein et al., 1938). This system was further developed to distinguish between initial lesions D1-D2, i.e., minor lesions often in the enamel and not in need of restorative treatment and manifest lesions D3, as described above, lesions in need of restorative dental treatment (Pitts & Fyffe, 1988). The International Caries Detection and Assessment System (ICDAS), a visual-tactical detection system, has attracted much attention in recent years (Ismail et al., 2007). The system was developed as there were concerns in clinical research about the ambiguity of many caries detection systems (Ismail 2004). For example, the DMFT system is highly dependent on the caries threshold used to report caries experience, which means that this is often underreported (Pitts & Fyffe, 1988; Fyffe et al., 2000). Other caries detection systems have been developed but have not gained widespread use.

1.1.5 OTHER ORAL DISEASES

Aside from dental caries, there are a number of oral conditions. These include but are not limited to periodontal disease, oral cancers, dental erosion, oral infections, and oral mucosal conditions (Lussi & Carvalho, 2014; WHO, 2023).

OTHER ORAL DISEASES – EPIDEMIOLOGY

Aside from dental caries, *periodontal disease* is the most common oral disease. Severe periodontitis affects around 796 million people, with a prevalence of 9.8% globally in 2017 (GBD 2017 Oral Disorders Collaborators et al., 2020). In Sweden, the prevalence of periodontal disease has decreased since 1973, according to repeated studies in the county of Jönköping (Norderyd et al., 2015). However, there has been a tendency towards an increase of the disease in the last decades, according to annual reports by SKaPa, with moderate and severe periodontitis affecting 12% and 11% of adults, respectively. Less than 10 %. of those aged 20-35 years had at least one periodontal pocket ≥6mm (SKaPa, 2022).

Tooth loss, although not technically an oral disease, is often used as a surrogate measure for the presence of oral disease. The prevalence of tooth loss globally is 3.3% with an estimated 267 million cases worldwide. Within the Swedish population, the number of totally edentulous individuals between the ages of 40-70 years has decreased since 1973, from 16% to 0.3% in 2013 in the county of Jönköping. Likewise, most 60-year-olds had almost complete dentitions in the same study (Norderyd et al., 2015). A study in an elderly population in Karlstad showed an increase in the number of individuals with ≥ 20 or more teeth between 2003 and 2015. Also, a decrease in edentulous individuals was noted (Critén et al., 2022). Dental caries is the primary reason for tooth loss in young adults, while periodontitis is the most common cause of tooth extraction for those aged 55-80 years in Sweden (SKaPa, 2022).

Another prevalent oral condition is *dental erosion.* According to a recent Swedish study, the prevalence of any sign of dental erosion in an adult sample (n=831) was 80% (Gillborg et al., 2020). A study in the United States found a similar prevalence (80%) (Okunseri et al., 2015). Progressive loss of dental hard tissue is often associated with dentin hypersensitivity, a sharp pain sensation upon exposure to stimuli (West et al., 2013).

OTHER ORAL DISEASES – ETIOLOGY

Periodontal disease is initiated through a process of bacterial colonization of the tooth, gingival and periodontal tissues (Socransky & Haffajee, 2003). Dental plaque build-up due to inadequate oral hygiene will lead to immune responses from the host, leading to inflammation of the gingival tissue. If adequate oral hygiene measures are not implemented, bone resorption will take place in the periodontal tissue and disease progression will follow (Kinane et al., 2003).

Dental erosion is defined in MeSH as a "progressive loss of the hard substance of a tooth by chemical processes that do not involve bacterial action". The chemical-mechanical process involves demineralization of the enamel and dentin through a combination of acid exposure and mechanical abrasion. Acid exposure occurs through food and beverage intake, or from acidic stomach contents that come into contact with the oral cavity through reflux or vomiting disorders (Lussi & Carvalho, 2014).

1.1.6 PATIENT- ASSESSED ORAL HEALTH

The value of measuring the social and psychological dimensions of oral disease was recognized decades ago by researchers (Cohen & Jago, 1976). Today, the importance of patient-assessed measures is established for both health policy and in clinical research and practice (Lohr & Zebrack, 2009).

Self-rated oral health can be assessed using single-item questions. Single-item questions regarding general health have shown good validity (Lundberg & Manderbacka, 1996). There are several well used questions for this purpose such as the number of teeth, chewing ability, and dental appearance (Ståhlnacke et al., 2003; Matsui et al., 2016).

ORAL HEALTH-RELATED QUALITY OF LIFE

Oral health-related quality of life (OHRQoL) has been established as a concept to measure the subjective aspects of oral health. It is measured through a variety of instruments, for example the Oral Health Impact Profile (OHIP), The Geriatric Oral Health Assessment Index (GOHAI) and Oral Impacts in Daily Performances (OIDP) (Slade & Spencer, 1994: Atchison & Dolan, 1990; Adulyanon & Sheiham, 1996).

Most available instruments measure the unfavorable aspects of oral health and their impact on OHRQoL. It is widely accepted that both external and internal characteristics such as values, coping strategies and social support systems impact how individuals view OHRQoL (MacEntee, 2006; Brondani & MacEntee, 2014).

Several models have been presented to explain the complex interplay between oral health, oral disease and internal and external factors. One of the first models used was Locker's model of oral health, an adaptation from the WHO classification of disability and handicap (Locker, 1988). Another well used model for explaining general quality of life that can be applied to OHRQoL is a model suggested by Wilson and Cleary in 1995. The model links OHRQoL through both clinically assessed and patient-reported outcomes. The model shows the complex interaction of biological and physiological variables, symptoms, function and health perceptions with mediating factors from the environment and inherent intrinsic factors such as personality and values (Wilson & Cleary, 1995).

A model put forth by MacEntee in 2006 represents a more existential view of oral health. This existential model portrays the multifaceted aspects of what constitutes oral health through a spherical representation (MacEntee, 2006). The sphere consists of three layers of equal importance, representing the complex and dynamic biopsychosocial interactions that constitute oral health. The outer layer represents environmental aspects and the interplay between social factors. The middle functional layer represents the potential that may arise from impairment and the limitations that it might entail. The inner layer consists of factors of oral health that are of importance to most people. The arrows represent the reciprocal relationship within and between layers as well as the fluctuation and dynamic process that occurs within the sphere. The model encompasses positive aspects that may impact OHRQoL and that may be lacking in other models. These positive influences include the support offered through social networks as well as adaptation and coping strategies.

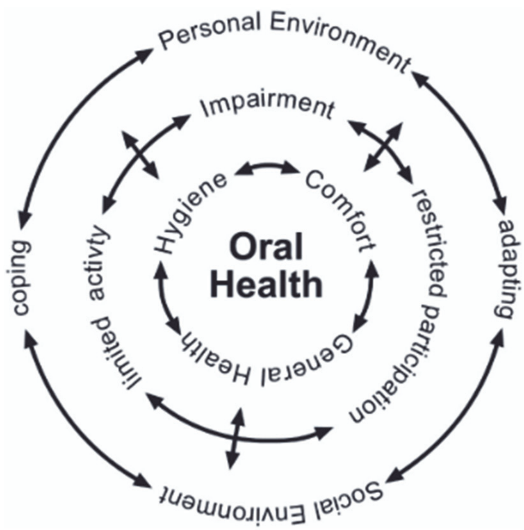

Figure 1. Existential model of oral health. Adapted from MacEntee (2006). Copyright © BASCD and Community Dental Health Journal. Reproduced with permission from the publisher Dennis Barber Ltd.

1.2 OBESITY

Overweight and obesity are defined as a surplus of bodyfat that may compromise overall health and wellbeing (WHO, 2000). There are different measures and classifications used for obesity, the most common being the body mass index (BMI). BMI is calculated by the division of weight in kilograms by the square of the height in meters in individuals (kg/m^2). A BMI of ≥ 25 kg/m^2 is considered overweight while ≥ 30 kg/m^2 is considered obese (WHO, 2000). Further subdivisions exist for BMI ≥ 30 kg/m^2, grading the severity and risk of comorbidities with obesity. A BMI of ≥ 40 kg/m^2 is referred to as severe or morbid obesity (WHO, 2000).

The BMI index is widely used in epidemiological research for its simplicity and applicability at population level. There are also specific measures, such as waist-hip ratio, waist circumference and waist-height, to account for the risk associated with, for example, central adiposity (Ross et al., 2020).

1.2.1 OBESITY – PREVALENCE

The global prevalence of obesity has increased steadily during the last decades with obesity estimates doubling in more than 70 countries between 1980 and 2015 (GBD 2015 Obesity Collaborators et al., 2017). In high-income countries, a higher obesity prevalence is observed among the poor (Ameye & Swinnenc, 2019). Conversely, in low-income countries higher obesity rates are noted among people of higher socioeconomic status, while the results are mixed in middle-income countries (Dinsa et al., 2012; Ameye & Swinnen, 2019).

According to estimates by the World Health Organization, one fourth of adults worldwide (25%) were overweight or obese in 2016. Among these, one in three (650 million) was regarded as obese (WHO, 2016). In Europe more than half of the population was considered overweight or obese that same year (WHO, 2022). According to a national survey in Sweden, more than half of the adult population (51%) was reported to be either overweight or obese in 2022 (Folkhälsomyndigheten, 2023).

1.2.2 OBESITY – ETIOLOGY

Obesity can be defined as an imbalance in the consumption and expenditure of energy i.e., the number of calories consumed and burned. However, the reality is more complex. Historically, obesity has only become of concern in recent years.

Before the past 40 years underweight was a greater problem globally (NCD-Risc, 2016).

The shift towards a positive energy imbalance is complex and mediated by both biological and environmental factors. The heritability of obesity was observed early on through family and twin studies (Stunkard et al., 1990). Since then, genome-wide studies have identified more than 1100 loci associated with BMI and obesity traits (Loos & Yeo, 2022). The fat mass and obesity associated gene (FTO) was one of the first genes to be discovered and has shown robust associations with obesity (Loos & Yeo, 2014; Loos & Yeo, 2022). The FTO polymorphisms are associated, for instance, with increased calorie intake and susceptibility to energy-dense foods (Loos & Yeo, 2014). Epigenetics, i.e., environmental changes that influence gene activity without altering the DNA, have also been proposed as a mediating factor for obesity (Pigeyre, Yazdi et al. 2016). Altogether, the combined discovered genetic polymorphisms only account for 6% of the BMI variance indicating that genetics and epigenetics alone cannot explain the current global obesity problem (Yengo et al., 2018). Hence, other explanatory factors must be considered. Dysregulation of the energy imbalance can further be impacted by age, sociocultural norms, medications, biomedical factors and psychological factors (Sharma & Padwal, 2010; Swami, 2015).

Socioeconomic disparities and inequalities are driving the obesity epidemic further. Disparities in income and education impact food choices (Rydén & Hagfors, 2011; Darmon & Drewnowski, 2015), at the same time as the food industry has made ultra-processed and energy dense obesogenic foods easily accessible at a low cost (Gupta et al., 2019). Modern lifestyle characteristics, such as reduced physical activity, sedentary behaviors, and increased screen time, have further enhanced the energy imbalance (Sun et al., 2021).

1.2.3 OBESITY – CONSEQUENCES

GENERAL HEALTH

Overweight and obesity are considered risk factors for a broad range of non-communicable diseases (GBD 2015 Obesity Collaborators et al. 2017). These include cardiovascular diseases, type 2 diabetes, hyperlipidemia, hypertension, kidney disease, and musculoskeletal diseases (Guh et al., 2009; GBD 2015 Obesity Collaborators et al., 2017; Khan et al., 2018). An increased risk of different cancer types, for example colon cancer, has also been observed among those with overweight and obesity (Guh et al., 2009; Bhaskaran et al., 2014; GBD 2015 Obesity Collaborators et al. 2017). Even small increases in BMI have been associated with cancer development (Bhaskaran et al., 2014). Obesity also increases the risk of maternal complications during pregnancy, the severity of Covid-19 infection and surgical complications (Bamgbade et al., 2007; Santos et al., 2019; Singh et al., 2022). Excess weight can also impair general quality of life, increase the risk of depression and lead to stigmatization and discrimination (Luppino et al., 2010; Stephenson et al., 2021; Gerend et al., 2022; Mejaddam et al., 2022).

Comorbidities and ill-health due to obesity increase the risk of premature death, with an estimated four million deaths being attributed to high BMI globally in 2015. The leading causes of death globally due to high BMIs are cardiovascular disease and diabetes (GBD 2015 Obesity Collaborators et al., 2017). Hence, obesity results in a considerable economic burden with increased health expenditure and medical and societal costs that impact both on individual and societal levels (Andersson et al., 2022).

ORAL HEALTH

The association between obesity and dental caries is uncertain. The results of studies in adults are contradictory (Idrees et al., 2017; Song et al., 2017; Barrington et al., 2019; Hamasha et al., 2019; Akarsu & Karademir, 2020). An issue is that obesity and overweight are often grouped together in these studies and reports on obese adults (≥35 kg/m^2) are scarce. Most of the reported data on obesity and dental caries has been on children and adolescent populations (Sabharwal et al., 2021). Systematic reviews have shown associations in the primary dentition among young children (Manohar et al., 2020), but not in older children with mixed dentition or in adolescents (Shivakumar et al., 2018).

Findings in systematic reviews support that there is a positive association between obesity and periodontitis (Suvan et al., 2011; Nascimento et al., 2015; Khan et al., 2018). The cause behind this association may be due to the properties of the adipose tissue (Kershaw & Flier, 2004). A large cross-sectional study showed that there were associations between obesity and periodontal disease in individuals 18-34 years of age, but not in older age groups (Al-Zahrani et al., 2003). However, a recent study reported that periodontitis did not co-occur with obesity but with other comorbid conditions like diabetes (Eke et al., 2018). Tooth loss has also been associated with obesity in some cross-sectional studies (Östberg et al., 2009; Vallim et al., 2021). These results were also verified by a recent meta-analysis showing a positive association between tooth loss, edentulism and obesity (Nascimento et al., 2016).

1.3 OBESITY TREATMENT

Obesity treatment aims to reduce weight and improve health outcomes. Although long-term weight maintenance can be difficult, even small reductions in overall body mass are considered beneficial for overall health (Jensen et al., 2014). The treatment options fall into two main categories, medical and surgical treatment.

1.3.1 MEDICAL TREATMENT

Medical treatment includes lifestyle interventions focused on the implementation of dietary and behavioral changes as well as increased physical activity to cause a caloric deficit. This is sometimes administered in conjunction with pharmaceutical treatment.

Dietary guidelines stipulate that a 600 kcal/day regimen is needed to achieve a weight loss of 0.5 kg a week (Yumuk et al., 2015). Different hypocaloric diets achieve similar success if adhered to, regardless of the macronutrient composition (Churuangsuk et al., 2022). Among dietary interventions, treatment with low energy (LED) and very low energy diets (VLED) is regarded as the most effective for weight loss (Parretti et al., 2016; Churuangsuk et al., 2022). LEDs and VLEDs constitute full meal replacements with the calorie intake restricted to 800-1200 kcal/day for LED and ≤ 800 kcal/day for VLED (Yumuk et al., 2015). Treatment with a VLED should be administered under the supervision of medical professionals with continued monitoring throughout the treatment (Yumuk et al., 2015).

Behavioral therapy together with dietary changes can improve both short-term and long-term weight loss outcomes compared with a control group (Look Ahead Research Group, 2014). Cognitive therapy, continued psychological support, and increased physical activity are tools used to further aid weight loss and maintenance (Jensen et al., 2014; Yumuk et al., 2015).

Overall, dietary changes may result in diabetes remission as well as improved blood glucose levels and cardiovascular outcomes (Parretti et al., 2016; Lean et al., 2018; Höskuldsdottir et al., 2022). The complications caused by medical treatment are predominantly minor and associated with the rapid weight loss and include hair loss, tiredness, lightheadedness, and impaired cold tolerance. Cholecystitis, a serious, although rare, adverse effect, has been reported (Parretti et al., 2016; Lean et al., 2018).

Apart from the lifestyle changes described above, support with adjunctive pharmaceuticals is available (Yumuk et al., 2015). Medical substances available in Sweden are orlistat, liraglutide and naltrexone/bupropion (Socialstyrelsen, 2023).

Recently, an antidiabetic drug (semiglutide) has shown promising results as a stand-alone anti-obesity drug (Wilding et al., 2021). Approved obesity drugs all cause modest weight loss, around 5%, compared with placebo (Khalil et al., 2020).

1.3.2 SURGICAL TREATMENT

Bariatric surgery or obesity surgery is an effective weight loss intervention for morbid obesity (BMI ≥40 kg/m² or BMI ≥35 kg/m² with the presence of comorbidities) (Welbourn et al., 2019; Höskuldsdottir et al., 2022). Internationally, including Sweden, the most common procedures are sleeve gastrectomy (SG) and Roux-en-Y gastric bypass (RYGB), with almost 5000 surgeries performed during 2022 in Sweden (Welbourn et al., 2019; SOReg, 2022).

There was an increase in bariatric surgeries in Sweden, until an all-time high in 2011. Since then, there has been a steady decline. An increasing number of surgeries are also privately financed. The decline is thought to be due to surgical staff shortage, inequalities in care between regions and, in recent years, the Covid-19 pandemic (SOReg, 2022).

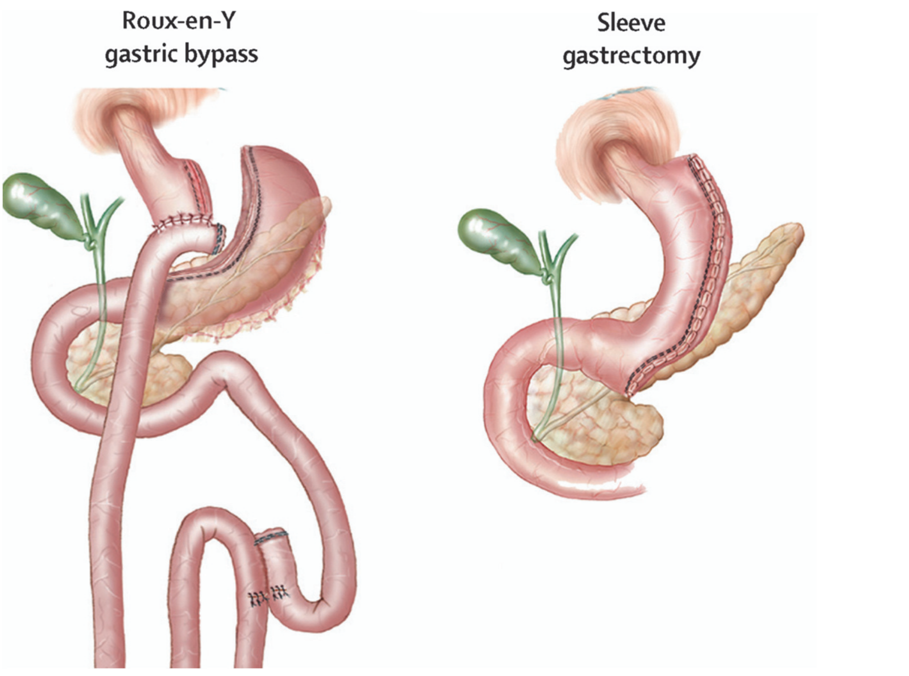

Figure 2. The most common surgical procedures Roux-en-Y gastric bypass and Sleeve Gastrectomy. Adapted and reprinted from Nuzzo et al.,2021 with permission from the publisher Elsevier Ltd.

Historically, several bariatric procedures have been developed since the 1950s, with the first gastric bypass performed in 1967. However, it was not until a decade later that the RYGB was developed. The SG was first developed as one part of a two-step procedure in high-risk morbidly obese patients; however, the results indicated that the technique caused substantial weight loss on its own (Phillips & Shikora, 2018).

The RYGB procedure involves creating a small pouch in the upper stomach, 15-25 ml in size. The larger part of the stomach and a part of the small intestine are bypassed, with the jejunum attached to the remaining small pouch. Anatomical alterations allow the digestive juices to enter the intestines at a later stage (Olbers et al., 2003). The SG procedure involves removal of a large part of the stomach, thus creating a tubular gastric pouch (Gagner et al., 2016). Both techniques are performed laparoscopically nowadays.

There are a few other bariatric procedures used worldwide, with the two most common after SG and RYGB being biliopancreatic diversion with duodenal switch (BDDS) and adjustable gastric banding (AGB) (Colquitt et al., 2014; Welbourn et al., 2019). The BDDS is performed on patients with BMI ≥ 50 kg/m^2 and is associated with a higher complication risk (Colquitt et al., 2014), while AGB is associated with a high reoperation rate (Himpens et al., 2011). AGB accounts for less than 5% of global surgeries (Welbourn et al., 2019). The AGB procedure has been discontinued in Sweden, while BDDS accounts for merely 40-50 surgeries annually (SOReg, 2022).

SURGICAL TREATMENT- OUTCOME GENERAL HEALTH

Both RYGB and SG lead to substantial weight loss (Welbourn et al., 2019; Höskuldsdottir et al., 2022). Total weight loss after two years is reported to be around 33.0 % for RYGB and 27.6% for SG, according to one study (Höskuldsdottir et al., 2022). This weight loss is not solely due to the restrictive or malabsorptive processes that occur following surgery (Nuzzo et al., 2021). Although the mechanisms are not fully understood, altered levels of gut hormones such as glucagon-like-peptide-1 and ghrelin appear to play a vital role (Pucci & Batterham, 2019).

The beneficial effects following weight loss surgery are well studied and include diabetes remission, improved cardiovascular outcomes and reduced mortality rates (Carlsson et al., 2020; Wiggins et al., 2020). However, despite the health benefits, the anatomical and physiological changes that occur may cause complications. The initial complications are due to the surgical procedure itself and include staple leak, bleeding, infection, bowel obstruction and strictures (Nuzzo et al., 2021; SOReg, 2022). Long-term complications that can develop include gastroesophageal reflux and a variety of diseases attributed to malabsorption and nutritional deficiencies. These include osteoporosis, anemia, hypoglycemia, and gastrointestinal diseases (Zhao & Jiao, 2019; Nuzzo et al., 2021; Lener et al., 2023).

Other studies point to an increased risk of psychological problems, such as self-harm, suicide and alcohol use disorder following surgery (Castaneda et al., 2019; Bramming et al., 2020). Overall, there are still knowledge gaps regarding the long-term effects of bariatric surgery and how it may impact different parts of the body.

SURGICAL TREATMENT- OUTCOME ORAL HEALTH

Whether and how the alterations to the gastrointestinal tract that occur following surgical obesity treatment impact oral health is scarcely studied. A recent register-based study in Sweden compared individuals who had undergone RYGB and SG (n=53643) with a matched cohort (Marsk et al., 2023). Individuals who had undergone bariatric surgery had more extractions, restorations and endodontic treatments following surgery compared with controls (Marsk et al., 2023)

Clinical studies on the subject are sparse. Studies on the impact of bariatric surgery on dental caries frequency have shown contradictory results, with one systematic review reporting an indication of higher risk, while a recent meta-analysis did not (Salgado-Peralvo et al., 2018; Ferraz et al., 2023). Changes in salivary composition and the microbiota have been noted after bariatric surgery (Lamy et al., 2015; Stefura et al., 2022).

Many studies have focused on periodontal changes. Some studies have reported associations with periodontal conditions such as an increase in periodontal pockets depth, clinical attachment loss, bleeding on probing (BoP) and in the number of bacteria associated with periodontitis (Marsicano et al., 2012; Sales-Peres et al., 2015). Self-reported tooth hypersensitivity and dental wear have also been noted (Marsicano et al., 2011; Netto et al., 2012; Ferraz et al., 2023). Meanwhile, other studies have not found these associations, (Sales-Peres et al., 2017; Yang et al., 2021). Recent systematic reviews have shown evidence of a transient change in the periodontal status i.e., an initial deterioration of periodontal health, which subsides with time (Colak et al., 2021; Ferraz et al., 2023).

Most studies included in the published systematic reviews in the field have short follow-up periods (≤ 6 months), report mainly on RYGB and have high heterogeneity in the study design and measures used; hence no definite conclusions can be drawn (Farias et al., 2019; Colak et al., 2021; Ferraz et al., 2023).

1.4 OTHER FACTORS OF IMPORTANCE FOR ORAL HEALTH AND OBESITY

Oral health and obesity have several background components in common. These components can be related to social and socioeconomic factors, as well as systemic conditions, behavioral components and gender.

1.4.1 SOCIOECONOMIC FACTORS

There is strong evidence of the association between social factors, socioeconomic status (SES) and health (Braveman & Gottlieb, 2014). A social gradient is present where those with higher income, educational level and employment status are healthier than individuals one step below on the social ladder (Marmot, 2005; Braveman et al., 2010; Stringhini et al., 2010).

The impact of socioeconomic factors on obesity is evident, both between and within countries (Ameye & Swinnen, 2019). Disparities in income within countries is associated with obesity i.e., in high-income countries, the poorest have the highest prevalence of obesity, while the situation may be reversed in low-income countries (Ameye & Swinnen, 2019). But as with health in general, a social gradient is present also in obesity (McNamara et al., 2017). Maternal weight, for example, was inversely associated with SES in a population-based study in France (Saurel-Cubizolles et al., 2022). A similar study in Sweden revealed that although obesity is rising across SES groups, the gaps are widening between educational levels (Lundberg et al., 2021). Lower SES throughout the life-course was also associated with a higher mean BMI in a recent meta-analysis (Newton et al., 2017).

Likewise, oral health is impacted by socioeconomic status. There is evidence of a SES gradient and oral health outcomes across welfare systems in Europe (Guarnizo-Herreño et al., 2013). An association between SES and dental caries has been shown in recent systematic reviews (Schwendicke et al., 2015; Costa et al., 2018). Moreover, a recent study showed that the incidence of tooth loss is higher among individuals with lower SES throughout the life, indicating a cumulative effect of low SES on oral health (Celeste et al., 2020). Socioeconomic factors, such as educational level, income level, and employment, are all associated with a risk of oral disease (André Kramer et al., 2018; Listl et al., 2018). Similarly, migration background is thought to be associated with an increased caries risk, with immigrants from the lowest socioeconomic position having the highest caries risk (Julihn et al., 2021).

1.4.2 MEDICAL CONDITIONS

Systemic diseases and conditions alter the risk and susceptibility to certain oral diseases and conditions (Twetman et al., 2002; Chapple et al., 2017; Sabharwal et al.z, 2021). For example, positive associations are seen between periodontal disease and those with uncontrolled diabetes (Eke et al., 2016). Likewise, salivary flow alterations can occur due to systemic conditions such as Sjögren's syndrome and rheumatoid arthritis, that may increase the risk of oral disease (Bardow & Vissink, 2015; Chapple et al., 2017). Certain medications and polypharmacy can also alter the risk through modification of the salivary flow (Närhi et al., 1992; Bardow & Vissink, 2015; Chapple et al., 2017).

1.4.3 BEHAVIORAL FACTORS

Diets containing ultra-processed foods have been associated with overweight and obesity in children, as well as in adults and adolescents (Juul et al., 2018; Liberali et al., 2020). Sugar-sweetened beverages (SSB), in particular, have been associated with overweight and obesity in both adults and children (Nguyen et al., 2023). Sugar consumption and SSB also play a substantial role in caries development (Bernabé et al., 2016; Chapple et al., 2017; Valenzuela et al., 2021; Moores et al., 2022).

Healthcare attendance is an important tool to manage and detect disease. However, individuals with obesity have been shown to delay or avoid seeking medical care due to fear of discrimination or perceived stigma associated with their weight (Olson et al., 1994; Drury & Louis, 2002; Puhl et al., 2021). For instance, there is evidence of a higher degree of non-participation among individuals with obesity in preventative screening programs for breast cancer and cervical cancer (Constantinou et al., 2016).

Similarly, dental attendance may be important to maintain good oral health and OHRQoL (Almoznino et al., 2015). Irregular dental service attendance and non-attendance was shown in a retrospective study to be associated with adverse caries experience and tooth loss in adults (Aldossary et al., 2015). In young adults, irregular dental visits were associated with high caries activity (Hagman et al., 2021). Furthermore, it has been shown that irregular dental attenders had fewer visits to healthcare professionals overall (Schmidt et al., 2020).

1.4.4 GENDER

There are inherent biological differences between the male and female sex, that influence health. Women live longer than men, yet are frailer (Hägg & Jylhävä, 2021). Gender differences exist in a number of non-communicable diseases, for example cardiovascular disease, cancer, diabetes and stroke (Mauvais-Jarvis et al., 2020)

The impact of obesity varies across genders. A British study showed that there was an association between overweight, obesity and depression in a dose-response manner in women, but the relationship was only true for men with BMI ≥ 40 kg/m² (Ul-Haq et al., 2014). Lack of societal ties has shown an association with waist adiposity and general obesity in women but not in men in a Canadian study (Hosseini et al., 2020) Women also seem to be more susceptible to weight gain due to life stressors than men (Udo et al., 2014).

Overall, women tend to visit their healthcare provider for weight loss management more frequently and be more dissatisfied with their weight than men (Tsai et al., 2016; Greaney et al., 2020). They also make up a large proportion of those seeking bariatric surgery (Kochkodan et al., 2018; Höskuldsdottir et al., 2020). Male bariatric patients tend to be older, have higher BMI and more comorbidities than their female counterparts (Kochkodan et al., 2018).

Gender differences in oral health have also been noted. In epidemiological studies women tend to have a higher prevalence of dental caries experience than men (Krustrup & Petersen, 2007; Hall-Scullin et al., 2017). However, men have a higher prevalence of untreated decay in studies (Krustrup & Petersen, 2007). The variability in caries experience between genders may be due to differences in overall health care use as well as dental attendance (Christensen et al., 2007; Thompson et al., 2016).

1.5 THE RATIONALE FOR THE THESIS

Against the aforementioned background, studies on the oral health of individuals with obesity present us with certain knowledge gaps. Furthermore, the oral health of individuals undergoing medical or surgical obesity treatment is sparsely studied. Longitudinal follow-ups of oral health following bariatric procedures are limited and few report on long-term outcomes. Furthermore, there is a need to address the patient perspective. This is often neglected and impacts on OHRQoL are seldom investigated in these populations.

2 AIM

The overall aim of this thesis was to study the oral health of individuals with obesity and how it is affected by medical and surgical obesity treatment.

SPECIFIC AIMS

1. To describe the oral health of individuals with increasing degrees of obesity and to explore the effect of modifying factors on associations between obesity and dental caries (Paper I).

2. To describe the oral health profile of individuals who have undergone common bariatric procedures, RYGB and SG (Paper II).

3. To examine how individuals treated with gastric bypass perceived their oral health and OHRQoL (Paper III).

4. To compare the effects of bariatric surgery (RYGB or SG) with medical obesity treatment on dental caries estimates from before until two years after the intervention (Paper IV).

3 MATERIAL AND METHODS

Paper I and Paper III were designed as cross-sectional studies. Paper II was a case series and Paper IV was a prospective longitudinal cohort study. All study material was collected in Region Västra Götaland, Sweden. An overview of the studies in this thesis is presented in Table 1.

Table 1. Overview of papers and methods in Papers I-IV.

Paper	**I**	**II**	**III**	**IV**
Study design	Cross-sectional	Case series	Cross-sectional	Non-randomized prospective cohort
Study participants	Women ≥ 35 kg/m^2, 18-35 years referred for obesity treatment	Individuals with RYGB or SG with worsened oral condition ≥ 2 years after bariatric surgery	Individuals with RYGB two years after treatment	Women two years after medical or surgical obesity treatment (from Paper I)
Sample size	n=118	n=14, ♀=12, ♂=2	n=1182 Participation rate 55.3% (n=653,♀=492, ♂=161)	n=113 Participation rate 58% (n=66)
Control group	Group I: BMI 35-39 kg/m^2	N/A	N/A	Medical treatment group
Data collection	Clinical examinations Questionnaire	Clinical examinations Questionnaire	Questionnaire	Clinical examinations Questionnaire
Data analysis	Descriptive statistics Analytic statistics using chi-square tests, one-way ANOVA with post hoc Tukey tests, and Spearman's correlation coefficients, linear and Poisson regression models	Descriptive statistics	Descriptive statistics Analytic statistics using chi-square tests, Mann-Whitney U-test, Spearman's rank correlation coefficients and logistic regression models	Descriptive statistics Analytic statistics using chi-square tests, Student's t-test, one-way ANOVA with post hoc Tukey tests, Wilcoxon's signed rank test, linear regression models

3.1 PARTICIPANTS

The thesis is based on data from three populations.

PAPER I AND IV

Paper I and IV are based on the same cohort, which was recruited from the Bariatric Surgery Substitution Nutrition study (BASUN), a non-randomized prospective cohort study (Höskuldsdottir et al., 2020), with the aim to compare and monitor the long-term effects of surgical and medical obesity treatment, in a clinical setting. The BASUN study recruited individuals referred to the Regional Obesity Centre in Region Västra Götaland for obesity treatment. Enrollment took place between May 2015 and November 2017. Inclusion criteria for study enrollment and treatment was BMI ≥ 35 kg/m^2, if obesity related comorbidities were present or BMI ≥ 40kg/m^2, regardless of comorbidities. The exclusion criterion was inability to understand the Swedish language. In total, 971 individuals (females, 73.8%) were included in the study. The treatment method was decided on the basis of medical status and patient preferences. From this cohort, all women aged 18-35 years of age were asked to participate in a sub-study of oral health and bone density. All women who accepted were consecutively included in the sub-study. Planned follow-up were 2, 5 and 10 years after obesity treatment. Paper I reports on data from the baseline examinations before treatment. Paper IV reports on the two-year follow-up.

PAPER II

This study population consisted of a convenience sample of individuals who had undergone bariatric procedures (RYGB and SG) ≥ 2 years ago, with patient-perceived and/or professionally registered oral health symptoms. The participants were identified by dental and healthcare professionals including doctors, nurses and dieticians in Region Västra Götaland. The exclusion criteria were other bariatric procedures, conversion from other bariatric surgery methods to RYGB or SG and not understanding the Swedish language.

PAPER III

This study population consisted of all individuals who had undergone RYGB during 2011 in Region Västra Götaland. Contact information for the subjects was obtained from the Scandinavian Obesity Surgery Registry (SOReg), a national quality registry for bariatric surgery in Sweden. All bariatric clinics in Sweden report demographic data and surgery type as well as complications up to ten years postoperatively. The registry contains data for around 98% of all operations performed in Sweden since 2007. The SOReg provided information on 1215 eligible participants. Of these, 14 were deceased, twelve had emigrated, two had protected identity and five had moved to a new address. Hence, 1182 individuals could be contacted by post. All were asked to participate in the study ≥ two years after their bariatric procedure. The time period was chosen to allow for an adequate amount of time to have passed since their operation, so that weight, diet and any short-term physiological changes may have stabilized.

3.2 DATA COLLECTION

3.2.1 MEDICAL DATA

Data on BMI for Paper I was retrieved from the main BASUN study. At the two-year follow-up (Paper IV) and in the case series (Paper II) the study participants were weighed (kg) on a common bathroom scale. Prior to the examinations the scale had been calibrated with a medical scale. The participants' height in Papers II and IV was self-reported.

Information about pharmaceutical treatment was obtained from BASUN for Paper I and IV. In Paper II, information on pharmaceutical treatment was obtained from the participants chairside. All participants in Paper II had undergone RYGB or SG and verification of the surgical treatment method was obtained through medical records.

3.2.2 DENTAL DATA

The odontological data collection was carried out in clinical dental settings by two calibrated and experienced dentists (NT, A-LÖ). The clinics were public dental clinics in Gothenburg, Mölndal and Skövde, all in Region Västra Götaland. Paper I, II and IV used the same study protocol for data collection. All sessions started with saliva sampling followed by the clinical examination.

SALIVA

Saliva was collected chairside. All participants were instructed not to eat, drink or brush their teeth an hour before the examination. Unstimulated whole saliva (UWS) was collected with the participant drooling passively into a measuring cylinder for 15 min. Instructions were given to relax as much as possible and not move the lips, tongue, or facial muscles. Stimulated whole saliva (SWS) was collected with the individual actively chewing on a paraffin pellet and spitting continuously for five minutes. The buffer capacity of the saliva was classified chairside using CRT buffer® (Ivoclar Vivodent, Lichtenstein).

Analysis to obtain total number of bacteria, streptococci, SM and lactobacilli counts per colony-forming unit (CFU)/ml of SWS was carried out at the Department of Cariology, Institute of Odontology, University of Gothenburg, Sweden. For total bacteria and total streptoccoci, blood agar respective mitis salivarius agar mediums where used. Growth occurred under anaerobic conditions at 37°C for seven days for total bacteria and for two days for total streptoccoci. Mitis salivarius bacitracin and rogosa agar were used as medium to cultivate SM and lactobacilli, respectively. Both were cultivated in anaerobic conditions at 37°C for two and three days. For all bacteria, results were expressed as colony-forming units (CFU/ml) saliva. All analyses were carried out by a biomedical analyst.

Analysis of electrolytes in SWS were performed at the Clinical Chemistry laboratory, Sahlgrenska University Hospital, Gothenburg Sweden. The analyses were performed on Cobas® 8000 (Roche Diagnostics), with saliva managed as serum sample.

DENTAL CARIES

Dental caries was recorded through visual dental examination and four digital bitewing radiographs. Prior to the recording, all tooth surfaces were professionally cleaned with a prophylaxis cup and prophy paste RDA 170. The teeth were flossed and air-dried. Dental caries was recorded using the visuo-tactical detection system ICDAS-II (Ismail et al., 2007). Caries recording was performed on all teeth with the exclusion of the wisdom teeth. A ball-ended explorer was used to aid the examination and carefully check for surface shape and surface loss of smaller cavities (Topping & Pitts, 2009). All four bitewing radiographs were taken in a standardized manner. The examination of the radiographs was done in a dimly lit room, on an Olorin Vista Line® monitor.

PERIODONTAL STATUS

Plaque was registered at four sites (mesial, distal, buccal, lingual) on the Ramfjord six index teeth, 16, 21, 24, 44, 34, and 36 (Ramfjord, 1967). Gingivitis and probing pocket depth (PPD) were assessed at two sites (mesiobuccal and distobuccal). All wisdom teeth were excluded. The PPD was measured from the gingival margin to the bottom of the gingival crevice with a Community Periodontal Index (CPI) probe (Löe, 1967).

3.2.3 PATIENT- REPORTED DATA

QUESTIONNAIRES

Information on sociodemographic characteristics, oral health symptoms, oral health behavior and self-assessed oral health was obtained through questionnaires for all papers. For Paper I, II and IV, the questionnaires were administered chairside and for Paper III through a postal questionnaire.

FOOD RECORDS

Collection of dietary data was performed for Paper II through a self-reported four-day food record prior to the dental examination. The record was posted to the participants and filled out at home. The participants were informed not to change their eating habits and eat according to their ordinary daily meal pattern. They were instructed to keep a detailed record of their eating during three weekdays and one weekend. Further instructions were given to record their meals and snacks with common household measures and scales with as much precision as possible.

3.3 VARIABLES

3.3.1 MEDICAL VARIABLES

BMI was calculated as kg/m^2. In Paper I, II and IV, BMI was used as a continuous variable, with further categorization into groups in Paper I. In Paper I and IV, pharmacological treatment was categorized into medication vs no medication.

For Paper IV, the participants were categorized by obesity treatment, i.e., medical treatment or surgical treatment.

3.3.2 DENTAL VARIABLES

DENTAL CARIES

Before the clinical examinations, an extensive calibration program was performed. The dentists (A-LÖ & NT) took part in repeated sessions using an eLearning tool provided for ICDAS calibration (https://www.iccms-web.com). Following online exercises, separate examinations were performed on 45 extracted teeth (225 tooth surfaces). Using linear weighted Cohens kappa (WK), inter-examiner reliability was calculated to 0.77 (95% CI 0.69-0.84). A re-examination was made after six weeks and the intra-examiner WK was 0.75 (95% CI 0.65-0.85) (NT) and 0.70 (95% CI 0.62-0.79) (A-LÖ), respectively. Five volunteers (630 tooth surfaces) were then recruited for visuo-tactical examinations which produced an inter-examiner WK of 0.88 (95% CI 0.85-0.92). Two of the volunteers were re-examined after two months by the main examining dentist (NT), producing an intra-examiner WK of 0.66 (95% CI 0.65-0.78). Calibrations discussions between two dentists (NT and PL) took place before the diagnostics of the dental radiographs. The bitewing radiographs of seven randomly selected study participants from the baseline cohort in Paper I were examined producing an inter-examiner WK of 0.73 (95% CI 0.66-0.80) and intra-examiner WK of 0.89 (95% CI 0.84-0.94) for both dentists.

Before the two-year follow-up of the dental examinations, the digital sessions on the ICDAS eLearning tool were repeated. Both examiners examined two patients with altogether 256 tooth surfaces. The findings were discussed chairside.

Dental caries was recorded at surface level according to the ICDAS-II seven grade system. The following visual grading score was applied: grade 0 constitutes a sound surface, grade 1-2 enamel lesions, grade 3 enamel lesion with breakdown but no visible dentin, grade 4 dentinal shadow (without apparent cavitation) and grade 5-6 severe caries lesion with distinct cavitation. A summary of the codes is provided in Figure 3. For the clinical examination all tooth surfaces were recorded (buccal, lingual, mesial, distal and occlusal). For the radiographic diagnostics three surfaces were scored (mesial, distal, occlusal).

Caries Severity Scores	Description
0	Sound tooth surface
1	First visual change in enamel
2	Distinct visual change in enamel
3	Enamel breakdown without visible dentin
4	Dentinal shadow, no visible cavitation
5	Distinct cavity with visible dentin
6	Extensive distinct cavity with visible dentin

Figure 3: ICDAS Caries Severity Scores (Topping & Pitts, 2009). Published with permission from the publisher S. Karger AG, Basel.

The radiographic and clinical recordings were weighted together for the surfaces evaluated in both the clinical and radiographic settings (mesial, distal, occlusal). When the scores deviated by a maximum of one step, the higher value was used. Greater differences were reevaluated. Sealants, different types of restorations, and missing teeth were recorded in accordance with ICDAS.

Variables for dental caries are presented in Paper I, II and IV. ICDAS values were presented as sound surfaces ($ICDAS_0$), enamel caries ($ICDAS_{1-2}$), dentin caries ($ICDAS_{3-6}$) and as total caries (ICDAS $codes_{1-6}$) in Paper I and IV. In Paper II, further subdivisions were made ($ICDAS_{1-2}$, $ICDAS_{3-4}$, $ICDAS_{5-6}$).

SALIVA

Salivary flow rate was calculated (ml/min). The buffer capacity of the saliva was classified as low/medium/high (Cheaib, Ganss et al., 2012).

Paper I and II present the salivary variables. The cutoff for low, unstimulated whole saliva was set at ≤ 0.1 ml/min, the low flow rate for stimulated whole saliva was set at < 1.0 ml/min and for very low flow rate < 0.7 ml/min (Bardow & Vissink, 2015). Bacteria counts were presented as numbers as well as dichotomized into counts for SM ≥ 1.000.000 CFU/ml and lactobacilli ≥100.000 CFU/ml. In the regression models in Paper I, logarithmic values of SM and lactobacilli were used.

PERIODONTAL STATUS

Presence of dental plaque was coded 0/1. Gingivitis was deemed to be present when there was bleeding on probing (BoP) on each tooth surface site (mesiobuccal, distobuccal) of the gingival sulcus. Gingivitis was coded 0/1. Periodontitis was considered to be present when PPD ≥3.5mm, and was coded 0-2 based on the PPD.

The percentage of total plaque, BoP and the number of sites with periodontitis were calculated.

3.3.3 DEMOGRAPHIC AND PATIENT- REPORTED VARIABLES

An overview of demographic and patient-reported variables is presented in Table 2. The overview also provides information on dichotomizations.

Table 2. Overview of patient reported variables, responses, dichotomizations and representations in different papers.

Variable	Responses	Dichotomization	Paper I	Paper II	Paper III	Paper IV
Age	In years		X	X	X	X
	In age strata		X	X	X	
Gender	Female/male			X	X	
Marital status	Married/ cohabitating Unmarried Divorced Widow/widower	Married /cohabitating Unmarried/not cohabitating	X	X	X	X
Education	Compulsory school Secondary school Higher education Other education	>9 years compulsory school Max 9 years compulsory school		X	X	
	Compulsory school Secondary school Higher education Other education	Post-secondary school >12 years Maximum secondary school ≤ 12 years	X			X
No. remaining teeth	No remaining teeth 1-9 remaining teeth 10-19 remaining teeth 20 or more remaining teeth Full dentition	≥20 remaining teeth <20 remaining teeth			X	
Chewing ability	Without difficulty With difficulty Unable	Without difficulty With difficulty/Unable		X	X	
Tooth brushing	Twice a day Once a day Not every day/ a few times a week Seldom/never	Twice a day Once a day/not every day/a few times a week/ seldom/never	X	X		X

Interdental cleaning	Every day 3-5 times/week 1-2 times /week Seldom/never	Every day/3-5 times a week 1-2 times a week/seldom never	X	X		X
Smoking	Never smoked Stopped smoking ≥ 1 year ago Sometimes Daily	Never smoked/stopped ≥ 1 year ago Sometimes/daily	X	X		X
Tooth hypersensitivity	Never A few times a year A few times a month Daily	Never/a few times a year A few times a month/daily		X	X	
Acid reflux	Never A few times a year A few times a month Daily	Never/a few times a year A few times a month/daily		X	X	
Vomiting	Never A few times a year A few times a month Daily	Never/a few times a year A few times a month/daily		X	X	
Dental visits last five years	Routinely/yearly 3-4 appointments 1-2 appointments Never	Routinely/yearly/3-4 appointments 1-2 appointments/never	X	X	X	X
Reason for last dental visit	Regular appointment Pain Other problems	Regular appointment Pain/other problems	X		X	X
Self-perceived oral health	Very good Good Average Bad Very bad	Very good/good Average/bad/very bad			X	

FOOD RECORDS

In Paper II, a registered dietician (SB) analyzed the food records using the Dietist Net Pro® software and the National Food Composition Tables version 20171215. The variables are presented as the number of meals, total energy intake and nutrient composition.

ORAL HEALTH RELATED QUALITY OF LIFE

The OHRQoL was recorded using the Oral Health Impact Profile (OHIP) (Slade & Spencer 1994; Slade, 1997). The Swedish version of the OHIP-49 was used in Paper III and the Swedish short version, the OHIP-14 in Paper II (Larsson et al., 2004; Larsson et al., 2014).

The OHIP-49 consists of forty-nine items. These items are divided into seven domains: functional limitation (9 items), physical pain (9 items), psychological discomfort (9 items), physical disability (9 items), psychological disability (5 items), social disability (5 items) and handicap (6 items). The OHIP-14 is an abbreviated version and contains fourteen items, with the same seven dimensions (two items per domain). The OHIP-49 and OHIP-14 are validated for English and Swedish populations (Slade & Spencer, 1994; Slade, 1997, Larsson et al., 2004; Larsson et al., 2014).

In both instruments, each item starts with the phrase: "Over the past year, how often have you experienced the following situations because of problems with your teeth, mouth, dentures and jaws?". The response variables are "never" (0), "hardly ever" (1), "occasionally" (2), "fairly often" (3), and "very often" (4). There are two methods of summarizing the OHIP scores (Allen and Locker 1997). In the additive method (OHIP-ADD), the scores are summed up based on the impact's severity. The OHIP-49 additive method has a maximum score of 196 and OHIP-14 additive method has a maximum score of 56. The closer the score is to the maximum the greater the impact on OHRQoL. The other method of summarizing scores is called the OHIP single count method (OHIP-SC) and involves dichotomization of responses. These are then summed up with a maximum score of 49 for the OHIP-49 and 14 for the OHIP-14. Similar to the OHIP-ADD, a higher score indicates a greater impact. For the OHIP-SC in Paper III, a dichotomization was made where the responses "never" and "hardly ever" were combined and assigned the value 0, while the responses "occasionally", "fairly often" and "very often" were assigned the value 1.

3.4 DATA ANALYSIS

Data control and management were carried out using Microsoft Excel® (Microsoft Corporation, WA, USA) prior to further analysis. In all papers the data analysis was carried out using the SPSS® (Statistical Package for Social Sciences), versions 22 (Paper III), 25 (Paper II) and 26 (Paper I and IV) (IBM Corporation, NY, USA).

For all papers, descriptive statistics were used to present data including numbers, percentages, means, standard deviations (SD), median values and ranges. The level of statistical significance for all tests was set to 0.05.

PAPER I

BMI was categorized into three groups BMI 35-39.9 (group I)/40-44.9 (group II) /≥45 kg/m^2 (group III). The differences between BMI groups and sociodemographic variables, medication, oral health habits were explored using chi-square tests. Mean differences in caries severity in the different BMI groups were analyzed using one-way ANOVA with post hoc Tukey-test. Tests of linear trends with contrast were carried out between BMI categories and clinical characteristics. The correlations between clinically and radiologically recorded caries were analyzed using Spearman's correlation coefficient.

Regression models were used to explore the association between BMI and dental caries. BMI was used as a continuous variable in linear regression models. Poisson regression was implemented to explore the role of confounders, using the least obese group as reference (BMI 35-39.9). Crude and univariate models were analyzed followed by full models adjusting for confounders. Separate Poisson regression analyses were performed to explore the association between BMI categories and initial caries, dentin caries, and total caries.

PAPER II

The analyses in Paper II were made using descriptive statistics. The data are presented as numbers, percentages, means, standard deviations (SD), median values and ranges.

PAPER III

Differences in proportions between genders with regards to socioeconomic characteristics, oral health status, oral health habits and oral health symptoms were explored using chi-square tests.

Missing data in questionnaires were handled and excluded from further analysis if >7 missing OHIP item were observed (n=9). The case mean imputation technique was used on all OHIP forms with 1-7 missing OHIP items (Fox-Wasylyshyn & El-Masri, 2005). Chi-square tests and the Mann-Whitney *U* test were applied to explore differences in the distribution of OHIP scores. To examine correlations between different OHIP subscales, Spearman's rank correlation coefficient was used. Internal consistency was calculated for all subscales using Cronbach's alpha.

Bivariate and multivariate logistic regression was used to explore the association between OHIP scores and different oral health variables. Adjustments were made for possible confounders in bivariate and full models. The OHIP-ADD outcome variable was dichotomized at median values. The variable OHIP-SC was dichotomized at having ≥ two impacts.

PAPER IV

The participants were categorized based on obesity treatment, both dichotomized (medical obesity treatment vs. surgical obesity treatment) and trichotomized (medical obesity treatment/RYGB/SG). Differences between the groups were analyzed using chi-square tests, Students t-test and one-way ANOVA. Changes in caries frequency, number of restored tooth surfaces and BMI over the study period were examined using Wilcoxon's signed rank test.

Linear regression models were used to explore the association between obesity treatment (surgical vs medical) and differences in dental caries frequency. Crude and adjusted models were used. Adjustments were made for possible confounders.

3.5 ETHICAL CONSIDERATIONS

Obesity can be perceived as a delicate subject. It is likely that some participants may have experienced discrimination in healthcare settings or by healthcare professionals prior to study enrollment. We have striven to treat all participants throughout the studies with empathy and respect. Feelings of guilt and shame may also be present; shame over body size and anxiety about the perceptions and judgments of healthcare professionals. This may have been a factor as the clinical studies progressed, if the participants felt that they had failed to adhere to recommendations or perceived that their own weight loss did not meet their own expectations. All participants in both the clinical studies and the postal study were informed that study participation was entirely voluntary and that they may drop out of the study at any time without further inquiries from the research group. The dental examinations were not associated with any risk for the study participants, aside from the discomfort that may arise from a routine dental examination.

All studies were approved by the Regional Ethical Review Board in Gothenburg (Paper I and IV, reg. no. 673-14; Paper II, reg. no. 237-16; Paper III, reg. no. 057-14), as well as the Swedish Radiation Protection Committee (Paper I and IV, reg. no. 14-39; Paper II, reg. no. 16-11). Signed informed consent was obtained from all participants in the studies.

4 RESULTS

PAPER I

Paper I presents data from baseline of the BASUN sub-study on oral health. The study sample consisted of 118 participants with a mean age of 27.8 years and mean BMI of 42.2 kg/m². Three out of five had an education ≤ 12 years, and more than half of the sample lived with a partner/spouse (55.1%). Their dental habits were poor with 35.9% reporting brushing their teeth less than twice daily and two thirds of the sample reporting irregular approximal cleaning. Around one in four did not attend regular dental visits and stated oral problems as the main reason for their last dental visit. One in five smoked daily and nearly half of the participants used medication regularly. Among individuals with the highest BMI (≥ 45 kg/m²), about one in two reported irregular dental attendance, with 42.9% stating oral problems/pain as the reason for their last dental visit. The characteristics of the baseline cohort are presented in Table 3.

Individuals with the highest BMI (≥ 45 kg/m²) had a significantly lower number of sound tooth surfaces ($ICDAS_0$) (p =0.045), and higher number of surfaces with dentin caries ($ICDAS_{3-6}$) (p = 0.001) and total surfaces with dental caries ($ICDAS_{1-6}$) (p = 0.046), compared with individuals with BMI 35-39.9 kg/m². Similar parallel linear trends were seen for all caries categories, i.e., an increasing frequency of caries lesions with increasing BMI, with the exception of enamel caries lesions ($ICDAS_{1-2}$). In total, the participants showed poor oral hygiene (50.3% plaque index, 34.5% BoP). Both SWS and UWS were within normal ranges; however, 10% of the individuals had a SWS < 0.7 ml/min and 36.4% UWS < 0.1 ml/min. The total group had moderate mean numbers of SM; however, the lactobacilli count was high, with one in five having a count of ≥ 100.000 CFU/ml. The salivary flow rate and buffer capacity did not differ between groups.

Both linear and Poisson regression models revealed positive associations between BMI and dental caries. In linear models this was significant for dentin caries and total caries ($ICDAS_{3-6}$, $ICDAS_{1-6}$), but not for enamel caries ($ICDAS_{1-2}$). Poisson regression models using individuals with BMI 35-39.9 (Group I) as reference for individuals with BMI 40-44.9 (Group II) and BMI≥45 (Group III), respectively, as independent variables showed a similar significant pattern for dentin caries and total caries but only for those with BMI ≥ 45 kg/m² These associations remained significant in both crude and fully adjusted multivariate models (adjusting for age, SES, oral health habits, salivary characteristics and medication). Hence, robust positive associations were seen between BMI and dental caries regardless of regression model and adjustments. An overview of full and crude models can be seen in Table 4.

Table 3. Sociodemographic characteristics and oral health habits of the baseline cohort by BMI group.

	Group I n=26 n (%)	Group II n=71 n (%)	Group III n=21 n (%)	*p*
Age 18 – 29 years	19 (73.1)	36 (50.7)	11 (52.4)	
30 – 35 years	7 (26.9)	35 (49.3)	10 (47.6)	0.127
Cohabiting (no)	13 (50.0)	31 (43.7)	9 (42.9)	0.608
Education ≤ 12 years (secondary school)	13 (50.0)	44 (62.0)	16 (76.2)	0.068
Medication* (yes)	16 (61.5)	29 (40.8)	10 (47.6)	0.284
Smoking daily or occasionally	6 (23.1)	15 (21.1)	5 (23.8)	0.972
Toothbrushing < twice daily	10 (38.5)	25 (35.7)	7 (33.3)	0.715
No regular interdental cleaning	15 (61.5)	50 (70.4)	14 (66.7)	0.665
No regular dental visits	5 (19.2)	14 (19.7)	11 (52.4)	**0.015**
Oral problems as reason for last dental visit	4 (15.4)	18 (25.4)	9 (42.9)	**0.037**

Group I: BMI 35-39-9; Group II: BMI 40-44.4; Group III: BMI ≥45.
** one or more of the following: glucose lowering treatment, blood pressure treatment, lipid lowering treatment, treatment for anxiety/depression, treatment with antipsychotics, pain medication, hypothyroidism treatment, ADHD treatment.*
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Table 4. Poisson regression models showing associations between obesity and dental caries, in crude and fully adjusted models.

Response	Adjustment	Group I* RR (95% CI)	Group II RR (95% CI)	Group III RR (95% CI)
Enamel caries (ICDAS1-2)	Crude	1	1.1 (0.9 – 1.4)	1.3 (1.0 – 1.6)
	Adjusted model	1	1.1 (0.9 – 1.4)	1.2 (0.9 – 1.7)
Dentin caries (ICDAS3-6)	Crude	1	1.3 (0.8 – 2.1)	2.4 (1.4 – 4.4)
	Adjusted model	1	1.2 (0.7 – 2.0)	2.1 (1.2 – 3.6)
Total caries (ICDAS1-6)	Crude	1	1.1 (0.9 – 1.4)	1.5 (1.1 – 2.0)
	Adjusted model	1	1.1 (0.9 – 1.4)	1.4 (1.0 – 2.0)

Group I: BMI 35-39-9; Group II: BMI 40-44.4; Group III: BMI ≥45.
Associations expressed as RR (rate ratio) and CI (95% confidence intervals) Confounders included in full models: socio-economic status, SES (cohabiting, educational level), general health (medication, smoking), oral health habits (toothbrushing, interdental cleaning, regular dental visits, reason for last dental visit), saliva characteristics (flow rates unstimulated and stimulated saliva, mutans streptococci count, lactobacilli count, buffer capacity). Reproduced from Paper I, with permission from the journal and the Taylor & Taylor & Francis Group: Slightly modified.

PAPER II

The case series comprised 14 participants (12 female, 2 males). The age range was 31-66 years and all had at least compulsory education. All were overweight or obese (BMI range 25.4-44.7 kg/m^2). Their bariatric surgery (13 RYGB, one SG) had been performed between two and 19 years earlier (mean 13 years).

Most stated that they visited the dental care regularly and brushed their teeth at least twice a day. Chewing difficulties (9/14) and issues with tooth hypersensitivity (6/14) were common. Dietary data revealed an energy intake within the normal range for the majority, with a mean meal frequency of five meals daily. Four individuals consumed more sucrose (≥ 10% sucrose /daily total energy intake) than the recommendations.

The clinical examination revealed that all participants had 16 or more teeth but only four had no missing teeth. All were registered with dental caries, with a great variation in the number of caries lesions (range 7-80). The majority of the caries lesions were enamel caries ($ICDAS_{1-2}$, 66%) but 11 of the 14 participants had severe caries lesions ($ICDAS_{5-6}$) in need of restorative treatment. Dental plaque (mean 59.2%) and BoP (mean 31.1%) were frequent. An overview of dental caries, filled tooth surfaces and periodontal status is presented in Table 5. The mean salivary flow rate was within the normal range for SWS, but the mean UWS was very low, 0.08 ml/min (median 0.06 ml/min). Despite this, a majority had a normal buffer capacity. Bacterial counts were generally high. Salivary electrolytes were all within the normal range.

The OHRQoL was captured using the OHIP-14 additive method. All stated negatively affected OHRQoL; however, a wide range of perceived impacts was noted (1-44).

Table 5. Overview of the participants with regard to dental caries, filled tooth surfaces and periodontal status.

	Tooth surfaces with caries			Filled tooth surfaces	Periodontal status	
Case	**Early stage decay** ($ICDAS_{1-2}$)	**Established decay** ($ICDAS_{3-4}$)	**Severe decay** ($ICDAS_{5-6}$)	**%**	**Plaque Index** (%)	**BoP** (%)
1	1	5	4	90.8	4.1	16.7
2	12	5	1	3.3	4.1	20.8
3	24	1	0	2.1	50.0	25.0
4	24	17	7	9.2	58.3	41.1
5	12	3	0	32.1	58.3	58.9
6	1	7	2	32.2	75.0	52.8
7	17	12	4	28.4	83.3	10.0
8	6	3	3	17.7	70.8	6.3
9	4	7	3	40.9	83.3	13.0
10	2	1	4	35.0	50.0	4.0
11	8	12	0	20.0	25.0	1.8
12	15	8	9	42.5	87.5	98.1
13	9	12	9	62.9	91.6	31.0
14	44	26	10	35.6	87.5	55.6

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PAPER III

Paper III reports on data from the cross-sectional postal questionnaire study. The study sample comprised 1182 individuals. The response rate was 55.3% (n = 653) after removing questionnaires that lacked signed informed consent (n = 8). The majority of the participants were women (75%). The mean age in the cohort was 47.6 years, which was somewhat higher than in the entire sample (44.3 years). One out of five only had completed compulsory school, and 35% were not cohabiting.

Self-perceived oral health was reported as average/bad/very bad by 45% of the respondents. Chewing difficulties were reported by 25% of the respondents. Tooth hypersensitivity was the most common ailment (27.8%), followed by acid reflux (16.1%). Vomiting episodes were the least common symptom affecting around one in ten (8.9%).

The OHRQoL was measured using the OHIP-49. A large majority of the respondents (78.9%) experienced at least one impact occasionally, often or very often. A few (n=54) stated no impacts on OHRQoL. The mean score on the OHIP-ADD was 30.3 (possible maximum 196) and on the OHIP-SC 15.6 (possible maximum 49). About one fifth of the participants reported more impacts and had a mean OHIP-ADD score that was considerably higher (91.4). More than 80% reported impacts in the dimensions physical pain and functional limitation, and more than 50% reported impacts on physical disability and psychological discomfort. Cronbach's alpha was > 0.8 for all subscales indicating high internal consistency. An overview of the OHIP and subscales is given in Table 6.

The association between single-item variables (problems prior to surgery, self-perceived oral health, chewing ability, tooth hypersensitivity, acid reflux, vomiting, no of teeth, dental visits, reason for last dental visit) and impacts on OHRQoL was analyzed using logistic regression. All these single-item variables were associated with perceiving negative impacts on OHRQoL using OHIP-ADD as the outcome variable in bivariate analyses. Similar results were found for OHIP-SC with a few exceptions (dental visit habits and problems prior to bariatric surgery). This overall pattern remained when adjustments for age, sex and socioeconomics were done.

Multivariate analyses including all the above described single-item variables and the possible confounders age, sex and socioeconomics in two separate full models revealed three statistically significant variables for OHIP-SC (self-perceived oral health OR 3.52, reason for last dental visit OR 2.26, tooth hypersensitivity OR 2.43) and four statistically significant variables for OHIP-ADD (self-perceived oral health OR 3.44, reason for last dental visit OR 2.70, tooth hypersensitivity OR 2.38, chewing ability OR 5.77).

Some gender differences were noted. Men stated more irregular dental visits (p = 0.020) than women and more missing teeth (p ≤0.001), while women reported more tooth hypersensitivity (p = 0.003) than men. Within the OHRQoL dimensions, women reported more impacts than men in the dimension physical pain. In the dimension social disability, the situation was reversed.

Table 6. Oral Health Impact Profile (OHIP-49) and subscales in participants having undergone RYGBP surgery ≥ 2 years ago. Maximum possible scores were 196 for OHIP-ADD and 49 for OHIP-SC.

		Score Mean (SD)	**Impact** n (%)
OHIP-ADD		30.3 (36.1)	590 (91.6)*
OHIP-SC		15.6 (14.6)	514 (78.7)**
OHIP 49 subscales	**Subscale (no of items)**		**Any impact*** n (%)
	Functional limitation (9)	6.8 (6.7)	557 (86.0)
	Physical Pain (9)	7.4 (7.4)	534 (82.9)
	Psychological discomfort (9)	3.7 (5.3)	348 (53.9)
	Psychological disability (5)	4.2 (6.4)	370 (57.5)
	Physical disability (5)	3.6 (5,6)	300 (46.6)
	Social disability (5)	1.9 (3.6)	226 (35.0)
	Handicap (6)	2.7 (5.0)	268 (41.5)

OHIP-ADD-49: number of individuals with any impact. OHIP-SC: Number of individuals with impacts very often/fairly often/occasionally
**Any impact "very often/fairly often /occasionally/hardly ever"*
***Any impact "very often/fairly often/occasionally"*
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PAPER IV

Paper IV reports on the two-year follow-up from the BASUN sub-study on oral health. Among the initial 113 participants who completed obesity treatment, 66 individuals (58%) took part in the follow-up examinations. The distribution of medical treatment was 39% (n = 26) and for surgical treatment 61% (n = 40). In the surgical treatment group RYGB was performed on 65% and SG on 35%. The total sample available at the two- year follow-up comprised 57% of those who had undergone medical treatment, and 60% of those who had undergone surgical treatment. Mean BMI had decreased statistically significantly for the surgical treatment group but not for the MT group.

At baseline, the level of education differed between the treatment groups with a greater proportion with low education in the surgical group. This was true regardless of whether three groups (MT 31%, RYGB 77%, SG 71%: $p = 0.002$) or two groups (medical vs surgical; $p < 0.001$) were analyzed. This difference was present also at follow-up. For the trichotomous division at follow-up, a significant association was only seen between MT and RYGB ($p < 0.001$).

At follow-up, differences were also noted in cohabitation status. Although the proportion of participants cohabitating had decreased in both the MT and surgical groups, more than half of the participants (54%) in the medical group reported cohabitating. In the surgical treatment group, the corresponding number was only 25%.

Regardless of treatment group, all participants showed worse oral hygiene at follow-up when compared with baseline. However, the surgical treatment group had more tooth surfaces with plaque (mean 70% of surfaces) compared with the MT group (mean 58%, $p = 0.024$).

All measures of caries - $ICDAS_{1-2}$, $ICDAS_{3-6}$, $ICDAS_{1-6}$ - increased in the surgically treated group, while no differences were observed in the MT group. Enamel caries ($ICDAS_{1-2}$) increased by a mean of 4.13 surfaces in the surgical group while a mean decrease of 0.77 surfaces was noted in the MT group. The differences remained significant regardless of whether three groups (MT, RYGB, SG, $p = 0.011$) or two groups (medical vs surgical., p=0.002) where used. Similar patterns were seen for total caries ($ICDAS_{1-6}$), but not for dentin caries ($ICDAS_{3-6}$).

In linear regression models, the difference in caries between baseline and follow-up was explored with obesity treatment dichotomized into medical/surgical treatment as the predictor variable. Crude associations were seen between obesity treatment versus difference in enamel and total caries. No significant corresponding association was seen for dentin caries.

Two covariates were significant per se in the fully adjusted models for differences in dentin caries: educational level and reason for the last dental visit. All other covariates were non-significant.

5 DISCUSSION

The main findings of this thesis were the overall impact of obesity and obesity treatment on oral health and dental caries. The association between BMI and dental caries were strongest in the most obese group (BMI $\geq$ 45 kg/m^2) and remained robust after adjustments (Paper I). Individuals who had undergone bariatric surgery struggled with oral health problems after the intervention (Paper II). This was further confirmed in Paper III, where those who had undergone bariatric treatment reported impacts on OHRQoL and clinically (Paper IV) had a higher frequency of caries lesions two years after surgery than at baseline. The associations between a surgical intervention and dental caries were consistent, although to some extent attenuated after adjustments. The same findings were not observed in the medically treated group.

5.1 METHODOLOGICAL CONSIDERATIONS

5.1.1 STUDY SETTING

Data collection for all papers was done in Region Västra Götaland, with one sixth of the Swedish population. The region consists of both rural, urban, and metropolitan areas. Participants were recruited from across the region for all the studies and the samples can thus be considered representative of obese and bariatric populations in Sweden.

5.1.2 STUDY DESIGN

Two studies had a cross-sectional design (Paper I and III), one was a case series (Paper II), and one had a longitudinal design (Paper IV). The studies contributed with knowledge on the clinical oral health status of the populations before obesity treatment (Paper I) and after obesity treatment (Paper IV) and the participants self-reported experiences of oral health after bariatric surgery (Paper II, III).

Cross-sectional studies (Paper I, III) offer a way to survey different areas and the design allows for associations to be observed; however, no causation can be inferred. These results should therefore be interpreted with some caution. A main objective of the case series (Paper II) was to generate hypotheses for further studies. It can be regarded as a retrospective study and was solely descriptive.

The longitudinal design in Paper IV provided an opportunity to study causal relationships. It also had a relatively long follow-up time compared with similar studies, which is considered a strength (Marsicano et al., 2011; Marsicano et al., 2012; Cardozo et al., 2014; de Moura-Grec et al., 2014).

The study designs in the thesis were chosen to complement each other, by using different quantitative methods. A qualitative design would have added valuable views from the participants perspective. Insights gained from participants living with obesity, or having undergone bariatric surgery, would give a broader understanding and deeper knowledge of why and how obesity, bariatric surgery and oral health interact (Macdonald, 2023).

5.1.3 STUDY PARTICIPANTS

A broad range of participant ages was represented in the thesis. In Paper I, the age span of 18-35 years was chosen for inclusion as BASUN planned a follow-up of ten years and the women – who constitute the majority of individuals seeking obesity treatment – should not have entered the menopause at the final examinations (Meurman et al,. 2009; Höskuldsdottir et al., 2020; SOReg, 2022). For Papers II and III, all adult ages and both genders were included. In Paper III, the mean age was slightly above 40 years, which seems reasonably representative of the mean age group of individuals seeking bariatric surgery treatment in Region Västra Götaland (Höskuldsdottir et al., 2020). Thus, the three study samples complemented each other regarding age and gender.

Oral health is rarely considered in medical studies. This deficiency could possibly be attributed to the separate organization of medical and dental care. The BASUN study therefore offered a unique opportunity to study oral health status within a larger medical context. The participants included in Paper I and subsequently Paper IV were included through BASUN, which recruited from the whole of Region Västra Götaland. Likely, the samples are representative of who seeks bariatric surgery in Sweden. However, a certain selection bias might be present, as not all individuals with obesity seek help. Another weakness was that all studies required good understanding of the Swedish language; hence, individuals with insufficient language skills were excluded. This means that generalizability is limited to some extent.

The participation rate in all the studies was acceptable, with all included participants completing the study in both Paper I and II. In Paper III, the response rate was 55.3%, which is in line with other postal surveys (Cook et al., 2009; Davey et al., 2016). On average, response rates have declined in recent years (Cook et al., 2009). Other reasons for not responding may be survey fatigue or perceiving the subject as sensitive (Edwards et al., 2002; Porter et al., 2004). In the follow-up study (Paper IV), the participation rate was 58%, which should be considered when interpreting the results. However, the distribution between the medical and surgical treatment groups was similar between baseline and follow-up, reducing the risk of bias. In Paper IV, 40% of the surgical group, and 43% of the MT group could not be contacted or declined participation for some reason. Participation was entirely voluntary in all studies, and we did not request that the reason for the dropout be stated for ethical reasons. The onset of the Covid-19 pandemic and subsequent societal consequences were, however, factors that may have affected participation at follow-up. Study attrition is always a concern in longitudinal studies (Kristman et al., 2004).

For Paper I and Paper IV, control groups were created within the sample. In Paper I, the group with the lowest BMI acted as the control group to be compared regarding caries prevalence with those with higher BMI (two groups). In parallel, the group of medically treated individuals acted as controls to the surgically treated individuals in Paper IV. A comparison between a normal-weight population and an overweight population would, of course, have contributed with additional knowledge and should be investigated in future studies. Based on the aims of studies II and III, with descriptions of clinical and self-perceived experiences of bariatric surgery, it was not appropriate to include a control group in these.

5.1.4 STUDY PROTOCOL AND INSTRUMENTS

The quality of the data collection was ensured in a number of ways. All the clinical studies in the thesis (Paper I, II, IV) used the same study protocol. Data collection was done in a standardized clinical setting. The time of day of the examinations was recorded and matched at the two-year follow-up (Paper IV). Ideally, data collection would have been performed at the same time for all participants, as to account for variations in salivary flow due to circadian rhythm (Dawes, 1972). However, logistically it was not possible to perform all examinations at the same time of the day.

Prior to the clinical examinations and the radiographic evaluation, a comprehensive calibration program was performed to ensure good intra- and inter-examiner reliability. Joint clinical recording sessions between the examiners were also repeated prior to the two-year follow-up to ensure agreement. The visual tactical caries detection system ICDAS-II was chosen as it has shown good validity and reliability for the assessment of coronal caries lesions (Ekstrand et al., 2018). ICDAS has been used in epidemiological caries research. The method has been further developed to facilitate its incorporation in clinical practice, resulting in the International Caries Classification and Management System (ICCMS) (Pitts et al., 2013).

As ICDAS is primarily a visual tactical detection system, it involves challenges to detecting approximal caries lesions and bitewing radiography was therefore added to the examinations. Bitewing radiography is considered an aid in caries diagnostics (Walsh et al., 2021). There is always a risk of under- or overestimation (Macey et al., 2021; Walsh et al., 2021). This risk may also depend, in part, on the examiner's experience and on how many dentists perform the examinations (Ekstrand et al., 2018). In the present studies, the examiners had adequate clinical experience and only two dentists carried out the data collection.

5.1.5 SELF-REPORTED DATA

Self-reported data from questionnaires were used in all studies, adding the participants' perceptions of their potential oral health problems, which clinical data cannot provide. However, with self-reported data there is always a risk of recall bias (Blome & Augustin, 2015). Social desirability is also a factor, i.e., giving more or less favorable answers depending on the subject and circumstance (Van de Mortel, 2008).

The filled-out questionnaires in Paper I, II and IV were answered in a clinical setting, where the participants possibly focused more on the task, resulting in completed forms. In Paper III, internal missing data for the OHIP occurred but was not common. Missing values for the OHIP were imputed using case mean imputation (Fox-Wasylyshyn & El-Masri, 2005). This technique was deemed suitable as each case is unique, but an individual's answers are interconnected.

For patient-reported measures and OHRQoL, well validated instruments (OHIP) and questions were used, including questions from the Living Conditions surveys, a nationwide survey done yearly since 1975 that documents health and living conditions in Sweden (Slade & Spencer, 1994; Statistiska centralbyrån, 1997; Slade, 1997; Larsson et al., 2004; Larsson et al., 2014). The number of questions in a form must always be balanced and limited so that the persons answering can maintain their focus and interest. This may mean that certain questions that would have been interesting are excluded; for example, questions about different oral health habits, such as fluoride use could have been penetrated more in detail. However, fluoride toothpaste is the standard in Sweden, and it can be assumed that the participants used it (Hugoson et al., 2005; Jensen et al.; 2012). Although fluoridated toothpaste use is common, optimal use varies (i.a., frequency, amount of tootpaste, toothbrushing time) (Jensen et al., 2012).

Dietary data were analyzed for the case series; however, not for the other papers. This limitation could impact the outcome (Barrington et al., 2019). Nevertheless, dietary information is self-reported, which poses a limitation *per se,* as there is a high risk of underreporting (Hill & Davies, 2001), which has been found for foods high in fat and sugar in particular (Krebs-Smith et al., 2000).Yet, bacterial counts, as presented in Paper I and II, could mirror the consumption of a carbohydrate rich diet (Beighton et al., 1996).

5.2 ON THE RESULTS

5.2.1 OBESITY AND ORAL HEALTH STATUS

Obesity is associated with impaired general health with both increased morbidity and mortality (GBD 2015 Obesity Collaborators et al., 2017). High BMI (≥45 kg/m^2) is associated with lower life expectancy across most age groups (Fontaine et al., 2003). Similar associations between obesity and oral health have been demonstrated in recent years (Nascimento et al., 2015; Khan et al., 2018; Vallim et al., 2021). Many risk behaviors, such as poor eating habits and smoking, can impair both general and oral health and are often interrelated (Sheiham & Watt, 2000; Marmot, 2005). Such clustering has been demonstrated in individuals with high BMI (Nihtila et al., 2016). This is in line with the findings in Paper I where the group with the highest BMI had the least regular dental attendance and stated pain/oral problems as the reason for their last dental visit. This may also be due to fear of discrimination from both dental and other health professionals (Olson et al., 1994; Drury & Louis, 2002; Puhl et al., 2021). A recent qualitative study showed that obese participants were likely to put life on hold and refrain from everyday activities (Haga et al., 2020). Visits to the dentist might thus be avoided as dental chairs have weight limits and an obese person might fear not fitting into the chair or breaking it and therefore postpones the visit until a more acute problem arises. Overall, there is likely an interplay of barriers causing dental care avoidance i.a., socioeconomic circumstances and/or, personal perceptions such as shame, values and beliefs (van der Zande et al., 2021).

Previous studies exploring associations between BMI and dental caries have been inconclusive in adults. While some studies support the present findings (Hamasha et al., 2019; Akarsu & Karademir, 2020), others do not (Idrees et al., 2017; Barrington et al., 2019). One reason for the conflicting results could be that the official cutoff for obesity (i.e. BMI ≥ 30 kg/m^2) was used, and in our study, associations were only seen at significantly higher BMIs. However, a systematic review found a positive association between caries and both low and high BMI (Hooley et al., 2012). Both underweight and obesity could reflect problematic eating behaviors. A factor in support of using a higher cutoff for BMI is that the least obese group in Paper I (BMI 35-39.9) had a similar mean caries prevalence (mean 3.2) as a sample of the general Swedish population (mean 3.7) (Norderyd et al., 2015).

In the light of these findings and the fact that the BMI of populations are increasing globally there is a need to further investigate the impact of a higher BMI (BMI ≥ 35 kg/m²) on aspects of oral health and oral health status (Folkhälsomyndigheten, 2023; NCD-RisC, 2016).

5.2.2 OBESITY TREATMENT AND ORAL HEALTH STATUS

The effect of obesity treatment on oral health status has hitherto been sparsely investigated and the few available publications have generated contradictory results. The reasons for the inconsistency might be found in varying registration methods, the definition for obesity and the follow-up periods.

The ICDAS-II seven grade system which was used for caries detection in the thesis (Papers I, II, IV) enabled detailed diagnoses with distinctions in the degree of enamel and dentin caries, while other studies in the field have used the DMFT system with its less sensitive score system (Marsicano et al., 2011; Marsicano et al., 2012; de Moura-Grec et al., 2014; Knas et al., 2016; Marquezin et al., 2022). In the present studies, caries across the whole span from small enamel lesion to severe caries lesions was measured, showing that associations were present throughout the spectrum. Just as for the obesity condition, the chosen cutoff for the BMI for obesity (most often ≥30 kg/m²) has probably also been significant for the analysis of the obesity treatment. In addition, most of the published studies had short follow-up periods (six months or less) while the two-year follow-up period (Paper IV) was likely a factor as the caries progression from a sound surface to dentin caries takes time (Mejàre et al., 2004).

In the present studies, differences in dental caries were found between the medical and surgical groups at the 2-year follow-up (Paper IV), in line with some earlier studies with shorter follow-up periods (Marsicano et al., 2011; Marquezin et al., 2022). Also, in a Swedish register study, individuals who had undergone bariatric surgery had received more dental treatments than the controls (Marsk et al., 2023). This is also in line with the findings in Paper IV where the number of fillings had increased statistically in the surgical group, but not in the medically treated group. Likewise, in Paper II, the examined participants exhibited a high proportion of decayed and filled surfaces. The background to these differences might be discussed from several aspects. The physiological and psychological, including health behavior, changes that may occur following bariatric treatment might cause a shift in the ecological balance within the oral cavity. This overload can lead to a change from a healthy balance to one where disease is present (Zaura & ten Cate, 2015). It is important to further explore the reasons for the differences in caries development between medical and surgical treatment that were seen at follow-up.

While differences in dental caries outcome at follow-up (Paper IV) were found between the two main treatment groups—medical and surgical——no significant differences were seen between the two surgical methods (RYGB, SG) in this outcome. There may not have been any differences, but another possible explanation is that we could not detect existing differences, as only a minority of the individuals had been treated with SG (i.e., lack of power). For example, an association between SG and gastroesophageal reflux has been demonstrated, which may lead to an increased risk of tooth erosion (Moazzez & Bartlett, 2014; Zhao & Jiao, 2019). Future studies should further investigate the impact of different surgical treatment methods on obesity.

5.2.3 PATIENT-REPORTED OUTCOMES

The OHRQoL in post-bariatric subjects has been sparsely studied in the past (Marsicano et al., 2011; Karlsson et al., 2018; Marquezin et al., 2022). In the case series (Paper II), a wide range of perceived impacts on the OHRQoL was demonstrated with all participants perceiving greater impacts than the Swedish population (Larsson, John et al. 2014). A majority (10/14) perceived their OHRQoL as corresponding to edentulous individuals (Larsson et al., 2014). Likewise, in the postal survey (Paper III), the level of impacts was similar to another group having experienced oral health problems that is; prosthodontic patients (John et al., 2014). In comparison, the general quality of life (QoL) of individuals who have undergone bariatric surgery is shown to improve after treatment, specifically during the first couple of years after surgery (Andersen et al., 2015). Thereafter, a gradual deterioration was observed; yet their QoL was still better than before treatment (Andersen et al., 2015; Sierzantowicz et al., 2022). Some studies have also noted that the QoL continues to be lower than in the general population after surgical treatment (Andersen et al., 2015; Sierzantowicz et al., 2022).

In the postal survey (Paper III), the overall OHIP scores were positively skewed with many individuals reporting relatively few impacts while a few reported many impacts, which is in line with other studies of Western populations (John et al., 2003; Bekes et al., 2009; Larsson et al., 2014). However, in the 20% reporting the most impacts, the scores were similar to those in individuals wearing full dentures (John et al., 2003). Similar to general QoL scores, the bariatric participants in our studies reported lower OHRQoL compared with general populations norms. One explanation could be an increased vulnerability in those who seek obesity treatment, which affects how they perceive both their QoL and their OHRQoL (Sierzantowicz et al., 2022). A similar pattern was found for the single-item question on self-perceived oral health, with the participants in our study reporting lower self-perceived oral health than in other recent studies (Molarius et al., 2014; Hakeberg & Wide Boman, 2017, Folkhälsomyndigheten, 2019).

Oral health problems are likely to impair OHRQoL (Larsson et al., 2004; Piva et al., 2018). This is in line with the findings in Paper III as all oral health symptoms were associated with impacts on OHRQoL. Tooth hypersensitivity was the most common symptom, similar to earlier studies of bariatric populations, where tooth wear and dental erosion were also reported (Heling et al., 2006; Marsicano et al., 2011; Alves Mdo et al., 2012; Netto et al., 2012). Some studies have also reported frequent vomiting episodes in individuals who have undergone bariatric procedures (Marsicano et al., 2011; Alves et al., 2012; Netto et al., 2012). In contrast vomiting was the least common problem, followed by acid reflux in Paper III (Yang et al., 2021). Generally, RYGB tends to reduce the occurrence of gastroesophageal reflux in bariatric populations (Zhao & Jiao, 2019). Still, some may experience these symptoms due to overeating or not chewing food properly, following RYGB (Fujioka, 2005). Individuals seeking obesity treatment have a high prevalence of eating disorders such as binge-eating (Conceicao & Goldschmidtx, 2019). Reemergence of these eating disorders may lead to weight gain in bariatric populations (Conceicao & Goldschmidt, 2019). Some participants may thus use vomiting as an unhealthy weight control measure (de Zwaan et al., 2010).

5.2.4 INFLUENTIAL AND MODIFYING FACTORS

Possible influential and modifying factors for the relationship between obesity and/or obesity treatment versus oral health were investigated in all papers (I-IV). These factors cover clinical, socioeconomic and demographic factors.

CLINICAL FACTORS

Saliva and salivary characteristics are known modifying factors that can increase or reduce caries susceptibility depending on the flow rate, quantity, composition and capabilities (Bardow & Vissink, 2015). In Paper I, a considerable proportion of the obese subjects had reduced salivary flow corresponding to hyposalivation. Obesity has been associated with reduced salivary flow rates in both children and adults (Flink et al., 2008; Modéer et al., 2010). Specific pharmacotherapy and polypharmacy are also associated with hyposalivation (Närhi et al., 1992; Smidt et al., 2010) and medication was common in all the clinical studies (Paper I, II, IV). Several systemic conditions also impact the salivary flow rate and composition

(Bardow & Vissink, 2015). This is in line with the findings in Paper I, as underlying systemic conditions and use of pharmaceutical drugs was frequent. Similarly, the unstimulated salivary flow rate among the case series participants was diminished and the stimulated salivary flow rate in the post-bariatric subjects in the case series was decreased; however, the stimulated salivary flow rate was within normal ranges for a majority of the individuals (Paper II). A recent systematic review of bariatric populations could not verify any changes in the salivary flow rate postoperatively (Farias et al., 2019). However, in that study, stimulated and unstimulated saliva were not differentiated, and the follow-up period for the majority of studies was only six months (Farias et al., 2019). Two studies report an increase in the unstimulated flow rate after bariatric surgery, contrary to our findings (Dupim Souza et al., 2013; Knas et al., 2016). This could possibly be due to reduced need for medication and fewer comorbidities (Segal et al., 2009). In contrast, the participants in our follow-up after two years (Paper IV) and almost half of the participants in the case series (Paper II) still reported frequent use of medication following surgical obesity treatment.

The salivary microbiota, SM and Lactobacilli, were analyzed for Paper I and II. Even if the microbial counts of SM were modest in Paper I, one in five had lactobacilli counts exceeding 100.000 CFU/ml saliva. In the case series (Paper II), participants also had high microbial counts. Caries development is not only dependent on the presence of SM and Lactobacilli *per se*; but, as previously discussed, there may be an interaction of an array of different bacteria (Tanzer et al., 2001; Takahashi & Nyvad, 2011). The oral microbiota composition in individuals with obesity differed from that in controls in a study (de Andrade et al., 2020). Altered levels have been noted following bariatric surgery in both the gut and oral microbiota (Adawi et al., 2022; Stefura et al., 2022). The importance of these changes for oral health has yet to be elucidated (Ballini et al., 2020).

In the case series (Paper II), the salivary electrolyte content was analyzed but no differences were found compared with a normal population (Klingberg et al., 2007). Also, in both Paper I and II, the buffering capacity of the saliva was analyzed with only few participants having low levels. The salivary buffer capacity and composition may be impacted by deficiencies (Lingström & Moynihan, 2003). These deficiencies may be present in both obesity and after bariatric procedures (Garcia et al., 2009; Nuzzo et al., 2021) with consequences for oral health. Another oral liquid with a possible influence on the caries process could be the gingival crevicular fluid (GCF), which should be further investigated in future studies (Modeer et al., 2011).

Previous caries experience, which has proven predictive of future caries, attenuated the regression models in Paper IV, even if not significant on its own in the models (Singh et al., 2013; Mejàre et al., 2014). Prior restorations also attenuated the relationships, as defective and rough fillings may accumulate plaque and therefore be predictive of future caries risk (Mejàre et al., 2014)

BEHAVIORAL FACTORS

Poor oral health habits such as infrequent tooth brushing and interdental cleaning were more common in the cohort followed over time (Papers I and IV), and more common than in the general Swedish populations (Jensen et al., 2012; Norderyd et al., 2015). The sample in Papers I and IV was relatively young (18-35 years at baseline) and other studies in young Swedes revealed similar plaque and BoP scores as in the present study (Ericsson et al., 2009; Hagman et al., 2021). It is possible that the preventive efforts of the dental care system were ineffective for these ages. However, poor oral health behavior was found in overweight European and Japanese samples (Nihtila et al., 2016; Tanaka et al., 2022).

Those who succeeded with their weight loss could perhaps be expected to take better care of their entire health but may also experience other and new problems after treatment (Gribsholt et al. 2016; Berg, 2019). Although surgical obesity treatment is an effective method for weight loss and reduced morbidity and mortality, all systemic conditions may not be resolved and new ones may develop, for instance, nutritional deficiencies and gastroesophageal reflux disorder (Zhao & Jiao, 2019; Wiggins et al., 2020; Nuzzo et al., 2021, Höskuldsdottir et al., 2022). This could lead to a down-prioritization of good oral health habits.

Neglecting oral care could also be attributed to psychological issues such as general depressive symptoms and anxiety (Anttila et al., 2006; Okoro et al., 2012). In turn, mental health symptoms may be associated with obesity and the severity of the obesity (Stunkard et al., 2003; Luppino et al., 2010). There is a high prevalence of individuals with depressive symptoms among those seeking bariatric treatment (Arhi et al., 2021). Experiencing psychological symptoms, such as fatigue, feelings of melancholy and lack of motivation can influence how a person prioritizes and views overall health and oral health.

Candidates for bariatric surgery may also have high expectations on life postoperatively (Dijkhorst et al., 2023). These expectations, if not met, may cause disappointment and ambivalence toward everyday life activities such as taking care of oral hygiene. Undoubtedly, life changes after surgery, and long-term bariatric patients perceive many challenges and adaptations that are needed to manage everyday life (Coulman et al., 2017; Berg, 2019). This could also change how participants prioritize different aspects of life, neglecting some and focusing more on others.

Dietary aspects could further explain the higher frequency of dental caries both before and after obesity treatment. A recent study showed that obese participants reported higher energy intake with excess intake of both carbohydrates and fat (Malek et al., 2019). Likewise, more frequent consumption of food, soft drinks and energy drinks have been noted in overweight populations (Nihtila et al., 2016). Problematic eating behaviors after surgery such as snacking or nibbling, especially on sugary foods, can increase the caries risk. Also, eating disorders are common in bariatric surgery candidates, and although they become less frequent after surgery, they may still be present or reappear (Conceicao & Goldschmidt, 2019).

SOCIOECONOMIC FACTORS

Socioeconomic factors have been widely recognized to influence both general and oral health (Braveman et al., 2010; Stringhini., et al. 2010, Braveman and Gottlieb 2014; Schwendicke et al., 2015; Celeste et al., 2020) Socioeconomic status can be measured through a wide variety of variables such as educational level, occupation, employment status, income, marital or cohabitations status and migration background (Statistiska centralbyrån, 2023).

When compared with national Swedish statistics, the educational level was lower in both the obese and bariatric populations studied in the thesis (Paper I, III and IV) (Statistiska centralbyrån, 2022). For the followed cohort, the educational level did not differ at baseline (Paper I) between the BMI groups (BMI 35-39.9; 40-44.9; ≥ 45). However, at follow-up (Paper IV), the surgically treated individuals had a significantly lower educational level than the medically treated. Education is important for both gaining and maintaining employment and reducing economic vulnerability (Gesthuizen & Scheepers 2010). Educational level is also an important factor for interpreting and implementing health information (Sherlock & Brownie, 2014). In Paper IV, educational level was a significant factor in fully adjusted regression models although it did not change the basic relationship between obesity treatment and caries. A recent Swedish study reported that one out of two bariatric participants had limited health literacy (Jaensson et al., 2021). Such limited health literacy has been associated with poorer oral health status (Baskaradoss, 2018).

Cohabitating may be beneficial for overall health in terms of social support gained (Hewitt et al., 2012), and facilitate adherence to dietary guidelines (Roos et al., 1998). The new situation after obesity treatment may influence relationships status. One study found that individuals who were single before bariatric surgery were more likely to enter new relationships, while those who were in a relationship before were more likely to break up from the partnership after their surgical treatment (Bruze et al., 2018). This could be in line with our findings, where cohabitation status had decreased in both surgically and medically treated individuals but was more common in the surgically treated individuals (Paper IV). Marital status also plays a role in economic inequality as not living with a partner or spouse increases the risk of economic strain and vulnerability (Hogendoorn et al., 2019). High economic vulnerability in turn may cause individuals to refrain from dental care (Molarius et al., 2014).

GENDER

The influence of gender on health has been established (Mauvais-Jarvis et al., 2020). In oral health, gender differences are also present with many epidemiological studies showing that women have higher prevalence of dental caries than men (Krustrup & Petersen, 2007; Hall-Scullin et al., 2017). A study revealed that the caries risk of young girls was higher until their teenage years, when a pattern reversal was observed (Kramer et al., 2016). This reversal might be due to different oral health attitudes and oral health behaviors that emerge between genders (Ericsson et al., 2012). Biological reasons may explain a part of this difference as tooth eruption times differ with girls getting their teeth earlier than boys, hence the teeth are at risk for dental caries for a longer time. Likewise shifts seen during, for instance, pregnancy can alter susceptibility to oral disease (Ferraro & Vieira, 2010).

Health-seeking behavior differs between men and women (Christensen et al., 2007; Thompson et al., 2016). Women are more likely to visit their dental care provider and having treatment while men have reported more irregular dental attendance (Wamala et al., 2006; Molarius et al., 2014). This is in line with the findings in Paper III, with men reporting fewer dental visits and fewer teeth. The more common health care avoidance in men might be explained by stereotypical gender roles and masculinity preventing them from seeking help (Himmelstein & Sanchez, 2016; Juvrud & Rennels, 2016).

In Paper II, symptoms of tooth hypersensitivity and impacts on physical pain were more common in the women. Different pain perceptions in men and women may have biological and/or psychosocial reasons (Dao & LeResche, 2000; Leaper & Friedman, 2007). Dentin hypersensitivity caused greater impairment of OHRQoL in the females in one study (Bekes et al., 2009). Hence, pain expression could be more acceptable for women as psychosocial expectations and norms differ between genders (Leaper & Friedman, 2007). A surprising finding in the postal survey (Paper III) was that the impact on social disability was greater in men than in women, i.e., the impact of OHRQoL on social aspects of life was greater in men. This difference may be due, in part, to the different coping strategies employed by men and women. Seeking emotional support is an important coping strategy for women facing challenges, for instance, dental problems. Women also tend to benefit from social relationships and are less likely to hide problems than men (Rosenfield & Mouzon, 2013), while men engage less in social activities and keep to themselves (Rosenfield & Mouzon, 2013). It is thus reasonable to assume that women would experience less social disability due to different strategies to deal with problems than their male counterparts.

6 CONCLUSION

In conclusion, the findings in this thesis indicate that both obesity and obesity treatment can impact oral health. Poor oral health, poor oral health behaviors, dental caries and impacts on oral health related quality of life are some of the challenges facing obese and bariatric populations studied in this thesis. The dental service should be aware of these problems and adapt preventive efforts for both individuals with obesity and those undergoing obesity treatments.

SPECIFIC CONCLUSIONS

- Poor oral health and higher caries levels with higher BMI was observed in young obese women (Paper I).

- Individuals who had undergone bariatric surgery had poor oral health status and experienced oral health problems long-term postoperatively (Paper II)

- A large proportion of individuals having undergone RYGB perceived problems with their oral health (Paper III) and impacts on OHRQoL were frequent (Paper II & III).

- A significant increase in dental caries was noted in surgically treated but not in medically treated individuals two years after obesity treatment (Paper IV).

7 FUTURE PERSPECTIVES

Obesity rates worldwide are rising steadily. More and more people are classified as obese, with those already obese becoming heavier. There will be a need to allocate resources to effective treatment methods like bariatric surgery. The findings in this thesis revealed that dental caries was more frequent in those with the highest BMI and that surgical obesity treatment may increase the frequency of dental caries and poor oral health, and result in greater impacts on OHRQoL. The need to consider these factors and explore impacts of other oral diseases when planning future research is evident. The focus should be on exploring the oral health of individuals with a BMI ≥ 35 kg/m^2, include a normal-weight control group and investigate modifying factors such as saliva, salivary composition, hormones and diet.

Longitudinal research is needed following bariatric procedures. The long-term effects of bariatric surgery on oral health still need to be explored in greater detail. For instance, studies on post-surgical diet, meal frequency, meal duration and its impact on oral health are of interest. Studies on shifts in the salivary composition and oral microbiota would also add valuable insights.

With the biomedical perspective still dominant in both odontology and medicine the individual's perspective is often forgotten. Therefore, future qualitative research exploring aspects of self-perceived oral health in both morbidly obese and bariatric populations is warranted. This will provide more profound knowledge on influencing factors.

The influence of different surgical methods on oral health and OHRQoL should also be explored in future studies. New surgical techniques for instance, SG, are growing in popularity and account for almost half the surgeries in Sweden, making it important to explore whether different surgical techniques *per se* impacts oral health and OHRQoL.

Lastly, this thesis shows that medicine and odontology are intertwined within this field. Dental professionals should be a part of the multidisciplinary team that assesses obese and bariatric surgery candidates. This would facilitate the planning of preventive care as well as the design of odontological intervention studies. My hope for the future is for a closer collaboration between general healthcare and dental care, as both perspectives are needed.

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