From DEPARTMENT OF DENTAL MEDICINE
Karolinska Institutet, Stockholm, Sweden

ASSESSMENT OF MASTICATORY FUNCTION AND NUTRITION IN PEOPLE WITH DENTAL IMPLANTS

George Homsi

2023

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Published by Karolinska Institutet.
Printed by Universitetsservice US-AB, 2023

ISBN 978-91-8016-672-0
Cover illustration: The apple has religiously symbolised the forbidden. In modern times, it represents health and beauty. For edentulous people, an apple is a longing. Perhaps the most common question edentulous people ask is whether they will be able to bite into an apple with their new implant prostheses. The cover illustrates a meeting between an implant and an apple, between function, nutrition, and quality of life, integrating my interest in art and design. The illustration of the implant is by Mats Ceder. The apple is part of Falling Apples, an artwork by Bigert & Bergström. The composition with permission from the artists. Dedicated to all the participants of the three studies.

First, do what is necessary. Then do what is possible. And before you know it, you are doing the impossible.

– Saint Francis Assisi

To my daughter Claudia

To my son Liam

To my family

For moments I did not spend with you...

ASSESSMENT OF MASTICATORY FUNCTION AND NUTRITION IN PEOPLE WITH DENTAL IMPLANTS

THESIS FOR DOCTORAL DEGREE (Ph.D.)

By

George Homsi

The thesis will be defended in public at the Department of Dental Medicine, Lecture Hall 4U, Alfred Nobels Allé 8, **Huddinge on Friday 16th June 2023, 9:00 am**

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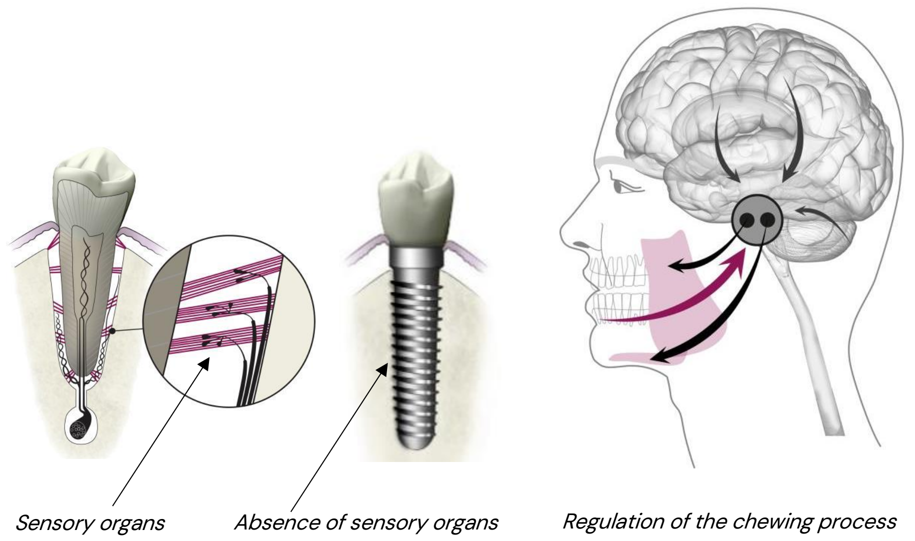
The thesis at a glance

Study	Aim	Key findings
I) Assessment of masticatory function in older individuals with bimaxillary implant-supported fixed prostheses or with a natural dentition: A case-control study.	To compare the masticatory performance of edentulous people treated with bimaxillary implant-supported fixed prostheses to those with a natural dentition using a simplified comminution test with hard viscoelastic test food and a mixing ability test.	Patients treated with bimaxillary implant-supported prostheses have reduced masticatory performance compared to those with a natural dentition, despite having been provided with satisfactory and well-functioning prostheses.
II) Subjective and objective evaluation of masticatory function in patients with bimaxillary implant-supported prostheses.	To investigate the association between subjective and objective measures of masticatory function in patients with bimaxillary implant-supported prostheses.	Although patients with implant-supported prostheses show poor masticatory performance, there is no agreement in the objective and subjective measures of mastication.
III) Assessment of the nutritional status, nutritional risk and eating habits among people with bimaxillary implant-supported fixed prostheses.	To evaluate the nutritional status, nutritional risk and eating habits of patients treated with bimaxillary implant-supported fixed prostheses compared to a natural dentate control group.	People with bimaxillary implant-supported fixed prostheses are at a higher risk of malnutrition, tend to have higher BMI and consume a significantly lesser variety of foods, especially fruits, compared to people with natural teeth.

Popular science summary of the Thesis

What happens when teeth are lost and get replaced with dental implants?

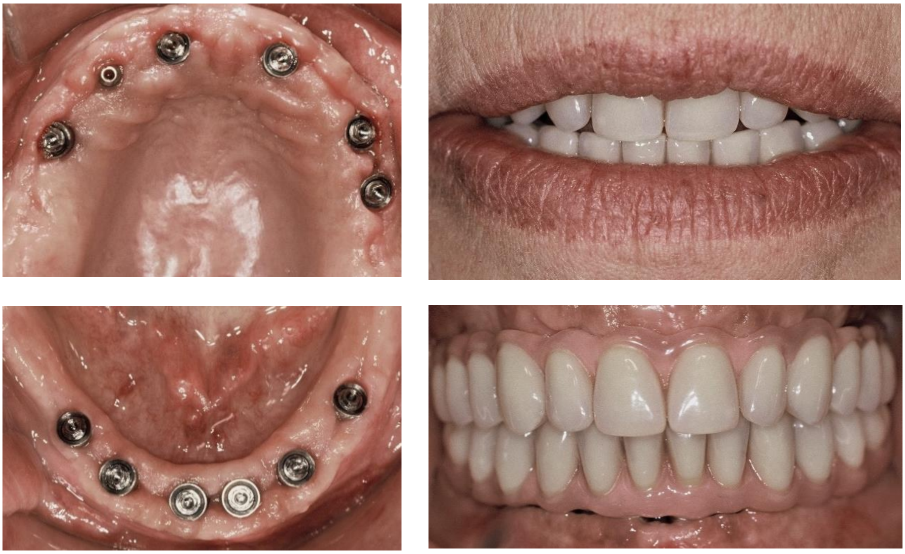
Studies have shown that people with chewing difficulties tend to be disabled, depressed, and have a poor quality of life. One of the mechanisms behind the chewing difficulties is suggested to be linked to the so-called mechanoreceptors, sensory organs of the teeth. The mechanoreceptors consist of nerve endings located in the connective tissue around the roots of the teeth. They are of utmost importance for the communication between the oral cavity and the brain. Those receptors are responsible for delivering information to the brain regarding the size, hardness, consistency, and texture of food. In turn, the brain is suggested to regulate biting forces and jaw movements to the chewing muscles, jaws, and other structures involved in the chewing process. When teeth are pulled out, the sensory organs are lost, and their communication with the brain is inhibited. As a result, the chewing function is impaired to some degree.



(Modified original artwork by Lina Trulsson, from Doctoral thesis of Joannis Grigoriadis. 2016)

A very important question is: To what extent does the lack of sensory organs around the teeth affect chewing, digestion, and nutrition? Consequently, can the signals be re-established when natural teeth are replaced with implant-supported teeth?

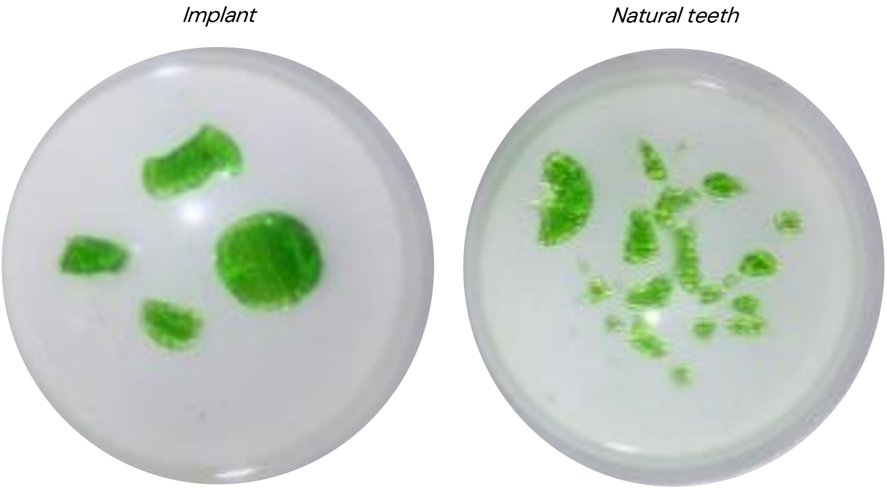
Patients who had lost all their teeth were included in the studies. The cause of tooth loss had been infections, extensive decay, trauma, and/or teeth grinding and clenching for a long time. The patients were treated with state-of-the-art treatment consisting of implant-supported bridges. The treatment lasted for six to twelve months. First, the screw-shaped titanium implants were placed in the bone of the jaws. After about three to six months of healing, the artificial teeth integrated into a bridge, consisting of a metal framework and teeth of plastic material, could be attached to the implants. All patients who participated in the studies had used their bridges for at least one year.



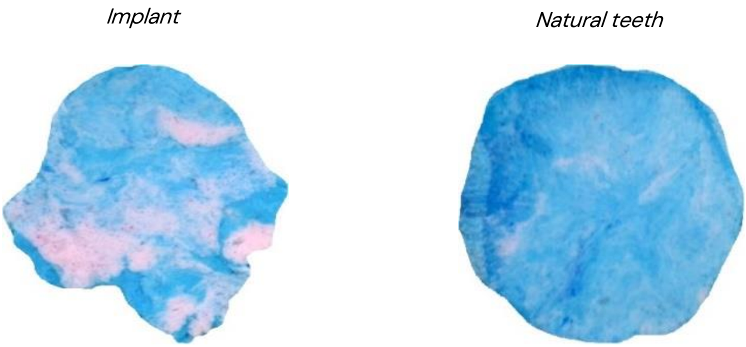
The images on the left show the upper and lower jaws just before attaching the implant-bridges. The images on the right show the implant-bridges being fixed in the mouth.

The researchers examined specifically the chewing performance, nutrition, and subjective measures such as quality of life. In addition to the group of patients with implant-supported teeth, a group still having their own natural teeth was included as a comparison. Chewing performance was assessed using a chewing test and a colour mixing test. The participants had to chew on specially made test food. After chewing, the food particles were spit out, and the number of particles was calculated using specialised software. The second test implied chewing, chewing gum with two layers of two different colours. A computer analysis could then show how well these two colours were mixed and thus the ability to mix food before swallowing.

The implant participants were satisfied with the bridges and stated a high quality of life. However, these participants showed poorer chewing performance. The particles were significantly fewer and larger before being swallowed. The same conclusion could be drawn from the second test. The colour mixing is generally better in the participants with natural teeth.



The chewing test: an implant patient to the left representing a small number of particles and a participant with natural teeth to the right with a higher number after 10 chewing cycles.



The color mixing test: an implant patient with poorly mixed colours to the left and a participant with natural teeth and better colour mixing to the left.

Further evaluation of these patients and their nutritional status showed that they were generally at a higher risk of malnutrition. Besides, they tend to have a higher BMI (Body Mass Index) and consume a lesser variety of foods, especially fruits, compared to people with natural teeth in the same age group. These findings are assumed to result from the impaired mastication, which can negatively affect their nutritional status. Besides, the implant patients, due to chewing difficulties, are assumed to avoid various foods with essential nutrients for balanced nutrition.

The lack of communication between the teeth and the brain can explain these results. Since the brain is not receiving any information from the mechanoreceptors due to the loss of the teeth, it cannot fully regulate signals to the oral cavity and other structures involved in the chewing process. However, preliminary research results show that we can still train these patients to activate other receptors in the oral cavity and the chewing system to compensate for the partial lack of sensory information.

When prostheses replace the hip, knee, and other joints in the body, patients usually go through long-term training to learn how to use the new joints. This training is not the case for tooth replacement. The researchers' future ambition is to establish a training program to optimise the function of new artificial teeth in the mouth. Their goal is a programme that will be easily accessible and applicable at dental clinics in Sweden and other parts of the world. Simply, to ensure the function of the new teeth, good nutrition, and high quality of life.

Abstract

Background

Treatment with bimaxillary implant-supported fixed prostheses is the state-of-the-art treatment of complete edentulism and replacement of natural teeth. However, the extraction of teeth results in the loss of periodontal mechanoreceptors (PMRs), normally located in the periodontal ligament. Complete edentulism implies a total absence of PMRs. The total lack of input from PMRs, which is involved in encoding relevant aspects such as the magnitude of biting forces, makes this group unique. The complete retaining of the prostheses and optimised restored function, anatomy, and aesthetics, mostly to the great satisfaction of the patient, make the group even more unique and interesting. However, the literature lacks studies assessing masticatory function and nutrition in completely edentulous people treated with bimaxillary implant-supported fixed prostheses. In fact, compared to other prosthetic treatments, such as hip and knee joint replacements, assessment routines for the outcomes of implant treatments are rare. The subjective and objective evaluations of masticatory function and assessment of nutritional status, nutritional risk and eating habits could be key factors for optimising masticatory function in people treated with implants.

Objectives

The thesis aims to assess the masticatory function and nutrition in people treated with bimaxillary implant-supported fixed prostheses compared to people with natural dentitions. Identifying differences and similarities between the groups may clarify functional impairments, nutritional deficiencies, and risks.

Material and methods

The thesis focuses on assessing various aspects of masticatory function and nutrition in people treated with bimaxillary implant-supported fixed prostheses compared to a control group of people with natural dentitions. Study I focuses on the establishment of a protocol/methodology for assessment of masticatory performance using a hard viscoelastic test food. Study II focuses on that agreement between the established objective measure of masticatory performance with a subjective evaluation of functional limitations and quality of life. Study III evaluates nutritional measures in people with bimaxillary implant-supported fixed prostheses. Nutritional status, nutritional risk and eating habits are assessed in comparison to an equivalent control group of people with natural dentition.

Results

The overall results of the three studies reveal significant differences between the groups. The masticatory performance is significantly lower in people treated with bimaxillary implant-supported fixed prostheses (Studies I & II). However, there is no correlation between the objective indicators of masticatory performance and the subjective

measures of any major limitation in function or quality of life (Study II). The differences are, however, present when analysing nutritional status, nutritional risk and eating habits (Study III). The participants in the implant group exhibited a significantly lesser variety of consumed food and a higher risk of malnutrition. Body Mass Index (BMI) was significantly higher and in the overweight range compared to normal weight in the control group. The risk of nutritional deficiency was significantly higher among participants with bimaxillary implant-supported fixed prostheses and in the range of high compared to moderate in the control group.

Conclusion

The success of treatment with bimaxillary implant-supported fixed prostheses, considered state-of-the-art treatment, is reflected in subjective measures of patient-reported satisfaction and high oral health-related quality of life. However, the masticatory performance is significantly impaired. Eating habits and nutritional status can be negatively affected, resulting in an increased risk of nutritional deficiencies and malnutrition.

List of scientific papers

This thesis is based on the following papers are referred to in the text by their Roman numerals:

I. Assessment of masticatory function in older individuals with bimaxillary implant-supported fixed prostheses or with a natural dentition: A case-control study.

   Homsi G, Kumar A, Almotairy N, Wester E, Trulsson M, Grigoriadis A.
   The Journal of Prosthetic Dentistry, 2021

II. Subjective and objective evaluation of masticatory function in patients with bimaxillary implant-supported prostheses.

   Homsi G, Karlsson A, Almotairy N,Trulsson M, Kumar A, Grigoriadis A.
   Journal of Oral Rehabilitation, 2022

III. Assessment of nutritional status, nutritional risk and eating habits among people with bimaxillary implant-supported prostheses.

   Manuscript

Contents

List of abbreviations

ANOVA	Analysis of Variance (A statistical term)
BMI	Body Mass Index (a measure of a person's weight relative to height)
CNS	Central Nervous System (the brain and spinal cord)
EMG	Electromyography (graphic recording of electrical currents in muscles)
IBS	Irritable Bowel Syndrome
JFLS-20	Jaw Functional Limitation Scale (an instrument for assessing limitations in the masticatory system)
MNA®	Mini Nutritional Assessment (a nutritional assessment tool)
OHRQoL	Oral Health-related Quality of Life
OHIP-49	Oral Health Impact Profile (an instrument for assessing Oral Health-related Quality of Life)
PMR	Periodontal mechanoreceptors (a sensory organ located in the periodontal ligament surrounding the tooth)
P-value	Probability value (a statistical term)
QoL	Quality of Life
SD	Standard deviation (a statistical measure)
SCREEN II	Seniors in the Community: Risk Evaluation for Eating and Nutrition (a tool for assessment of nutritional risk)
TMD	Temporomandibular joint disorders
TMJ	Temporomandibular joint
VOH	Variance of hue (a measure of mixing ability)

1 Introduction and literature review

1.1 The History of dental implants

Replacing teeth with various types of implants has a history of thousands of years. Among many examples, the ancient Egyptians attempted c. 2500 BC to stabilise periodontally damaged teeth using a golden ligature. Around 600 AD, the Mayan populations, introduced pieces of shells as a replacement for teeth; radiographs show compact bone formation around those primitive implants. In 300 AD, the Phoenicians implanted teeth carved out of ivory and stabilised by a gold wire to replace lost teeth. Later, during the 16th to 19th centuries, teeth from cadavers and unprivileged people were transplanted. In the 18th century, transplantation of teeth with non-fully developed roots from one human to another was performed. Various materials, such as silver, gold, porcelain etc, were also used (1).

Several attempts to retain artificial teeth have been made in the recent century and many variants of dental implants have been introduced. Those implants have been classified as subperiostal implants, endosseous implants such as blade and transosteal, submucosal implants and transdental fixation (2). The outcome was unpredictable, and the treatment often resulted in complications. However, in the mid-1960s and 1970s, respectively, Brånemark and Schroeder established the concept of osseointegration and implant treatment with **cylindrical endosseous implants**. It was only then that implant treatments became a predictable and stable option for replacing lost teeth (2-9).

1.2 The concept of osseointegration

During implant installation, a series of injuries are caused in the mucosa, the cortical and the cancellous bone. In turn, the tissues react with an inflammatory reaction whose purpose is eliminating damaged tissue and initiating the regeneration of healthy tissue. The large contact area between the implant and the alveolar bone tissue establishes proper initial so-called primary stability. This rigid connection is considered one of the keys to the success of osseointegration. A process of remodelling of the tissues occurs for at least six weeks, during which the amount of new highly mineralised bone increases (10). During functional loading, the structural and functional connection between the bone tissue and implants is called **osseointegration** (4, 6). Eventually, the bone tissue establishes an **ankylosis** around the implant. Besides this rigid fixation, a healing process occurs in the mucosa around the titanium implant. A mucosal attachment sealing, protecting the bone tissue from undesirable substances from the oral cavity, is established. Thus, a junctional epithelium similar to the one found around the natural tooth is developed and attached to the surface of the implant, forming a peri-implant tissue resembling the periodontal tissue (6, 9).

1.3 Mastication and oral sensorimotor control

Mastication involves several major muscle groups: The temporal, the masseter, the medial pterygoid, the lateral pterygoid and the digastric. These muscles cooperates, mainly innervated by the mandibular branch of the trigeminal nerve, to achieve successful and safe mastication and swallowing. Besides masticatory muscles, several receptors are involved in regulating the process of mastication.

Muscle spindles are integrated into the central parts of the muscles. The masticatory muscles spindles are only located in jaw-closing muscles such as the masseter and temporalis (11). The cell bodies of the muscle spindles are located in the trigeminal mesencephalic nucleus and are specialised in monitoring changes in the muscle length (12).

Mechanoreceptors in the Temporomandibular joint (TMJ) are located in the joint capsule. Among many, Golgi organs, Pacinian corpuscles, and Ruffini nerve endings can be present (13). The involvement of those receptors in mastication seems to be restricted to avoidance of joint displacement when exposed to extreme jaw movements, such as opening, laterotrusion and protrusion (14).

Mechanoreceptors in facial skin, lips, and oral mucosa are involved in providing proprioceptive information during the speech, chewing and jaw movements. For instance, signalling contact between the lips, the deformation of the skin, and air pressure generation during orofacial functions such as speech (15, 16).

Periodontal mechanoreceptors (PMRs) whose absence around dental implants is the fundamental difference between dental implants and natural teeth. Those are nerve endings located in the periodontal ligament connecting the cementum of the root to the alveolar bone (17) (Fig. 1). PMRs are slow-adapting, mostly resembling Type II Ruffini (18), low threshold receptors. PMRs react when forces that are applied to teeth cause tension in the periodontal ligament (19-21). Therefore, PMRs are mainly concentrated in regions of the ligament subjected to stretch and loading when teeth are in use (17, 22). Movements of 2-3 µm are supposed to trigger PMR responses (19, 23). In addition, PMRs react differently depending on the direction of the stimulus, and it is assumed that directions used when chewing are the most optimal to stimulate PMRs (24). The CNS can, with a very high precision detect the stimulated tooth, although half the number of the periodontal receptors react to stimuli from adjacent teeth (22).

Although chewing involves several teeth, and individual PMRs may respond to forces applied at other teeth, PMRs can encode information about the load and direction of forces to which each individual tooth is exposed (25-27). Besides, PMRs show the highest sensitivity at force levels below 1 N for anterior teeth and about 3-4 N for posterior teeth (28, 29). These data indicate that PMRs respond mainly during the initial contact with food.

However, PMRs seem to have a threshold of saturation that also increases gradually from the incisors and posteriorly to the molars (30). Further, PMRs provide less information about forces involved in splitting and crushing food. However, sudden deprivation of sensory input from PMRs, caused by anesthetised periodontium, affects the jaw kinematics and muscle activity of the masseter muscles. PMRs are supposed to contribute to approximately 20 % of the total EMG activity of the masseter muscle during the jaw-closing phase (31).

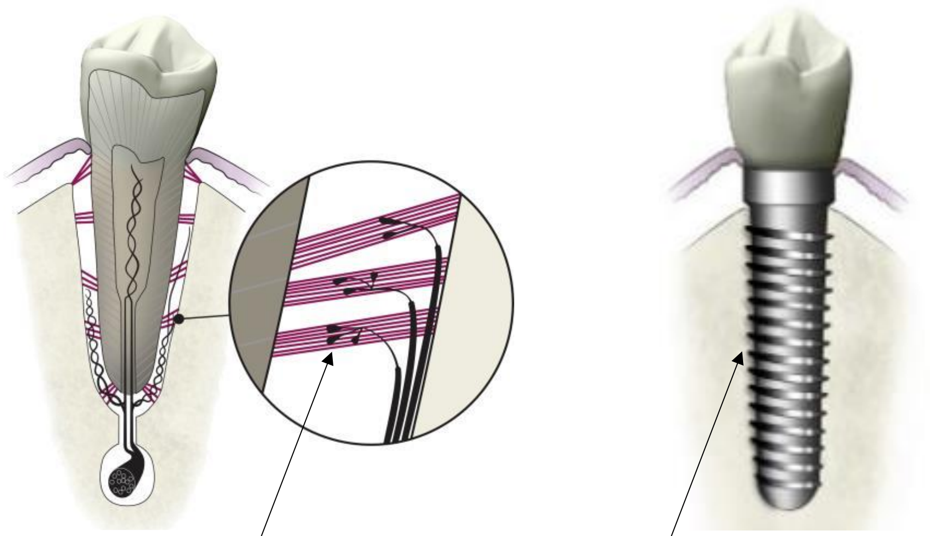


Figure 1. A. *A natural tooth with periodontal mechanoreceptors (PMRs) embedded in the periodontal ligament surrounding the root of the tooth and signaling information about tooth loads.* ***B.*** *An (ankylotic) osseointegrated implant with no PMRs present around the implant. (Modified from original artwork by Lina Trulsson, from thesis of J. Grigoriadis, 2016)*

Several sense organs in the orofacial structures are involved in controlling oral motor behaviours such as biting, chewing, and speech. Specifically, the interaction between PMRs and the central nervous system (CNS) is crucial for adapting the chewing pattern to food hardness since PMRs play an important role in controlling the muscles of mastication (32-35). PMRs are even involved in the sensorimotor control during movements involving fine tuning of mastication, such as food positioning (28, 30, 36). Studies using microneurographic recordings have detected that human PMRs provide temporal, spatial, and intensive information about tooth loads (25-27, 29, 30, 37). The cell bodies of the PMRs are located at two different sites: the trigeminal ganglion (TG) and the trigeminal mesencephalic nucleus (MN) (18, 38). The projection at MN seems minor and is finally transmitted to the cerebellum leading to an unconscious reflex (38). Most of the signals transmitted through TG are relayed through the thalamus to the somatosensory cortex. Initially, the input seems to be projected tooth by tooth and later in the cortex in terms of half arches instead (38). A series of experiments in the past have suggested that semiautomatic, repetitive movements, like swallowing and mastication, have mainly two basic characteristics, i.e., they contain a pool of neuron assemblies in the brainstem called the central pattern generators (CPGs) and a feedback system (32, 34, 39). The CPGs located in the pons and medulla of the brainstem are responsible for the intrinsic pattern of jaw opening, jaw closing and the associated movements of the tongue, facial and jaw muscles (40) (Fig. 2).

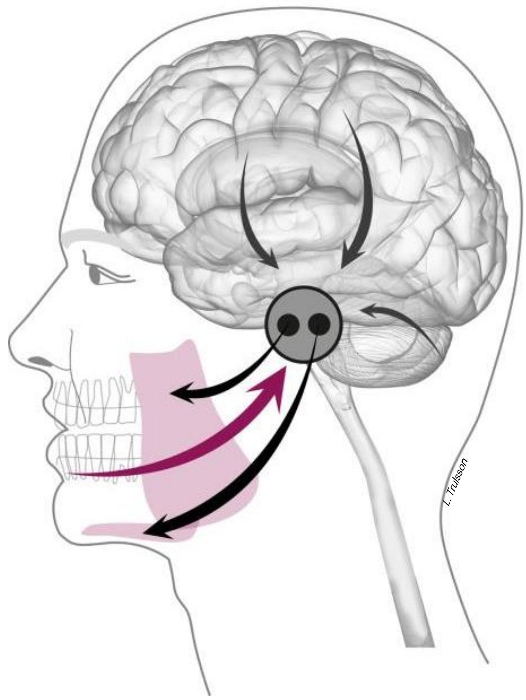


Figure 2. *An overview of sensory motor regulation of oral motor behaviors.*

As mentioned earlier, an implant is ankylosed, and movements are only possible within the bone with no involvement of connective tissue normally presented in the periodontal ligament. Therefore, features facilitated by the periodontal ligament, such as the nociceptive reflex, are inhibited (41). Further, sensory perception, jaw motor control and jaw function regulated by the periodontal mechanoreceptors (PMRs) are also impaired (42, 43).

1.4 Edentulism and implant treatment

Edentulous people have benefited to a great extent from the treatment with dental implants. Besides difficulties adapting to complete dentures and lack of retention and stability (44), the resorption of the residual alveolar ridges is the cause of considerable complications (45). Especially in the edentulous mandible (Fig. 3), the use of implants has implied valuable improvements. Treatment with two-implant overdentures is proposed as the first-choice standard of care for the edentulous mandible. However, this treatment is considered the minimum yet not the most optimum (46).

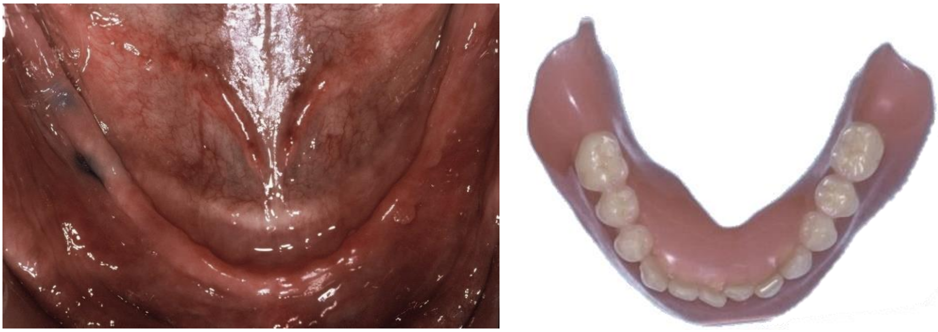


Figure 3. *An atrophic edentulous mandible implying considerable limitations and discomfort due to lack of retention for the removable prosthesis.*

Treatment with implant-supported fixed prostheses is considered state-of-the-art to treat edentulism and try to simulate the natural situation of the dentition. This treatment has been proven to have a great degree of satisfaction and a high long-term success rate (47-49).

With the establishment and predictability of osseointegration, the interest of treating people was spread worldwide. A race against new designs, surfaces and materials was started. However, Brånemark was clear about the "decisive effects of functional load on the healing process and remodelling of bone marrow rather than focus on the hardware" (41). Unfortunately, these features and aspects of function have sometimes been neglected, and less focus has been set on evaluating masticatory function and nutrition among people treated with dental implants. At some point, it was perhaps assumed that implant-supported prostheses are equivalent to natural teeth.

1.5 Health and quality of life

Besides global variability in dental health, there are cultural differences in the impact of teeth on social codes. In some cultures, tooth modification, such as tooth sharpening, is practised as a symbol of various beliefs and social positions. Other cultures support crowning front teeth with gold crowns as a symbol of wealth and status. For decades, bleaching and veneers have symbolised status and beauty. Besides, due to large economic gaps in societies, dental health symbolises, to a larger extent, economic inequalities. The involvement of the masticatory system in multiple other functions makes it complex and important. Besides chewing, the system participates essentially in vital functions such as respiration (50), digestion, and speech. Non-verbal communication, such as smiling, laughing, facial expressions, and yawning, engage the masticatory system to a high level. On a higher level, it is suggested that poor chewing is associated with cognitive impairments and dementia in the elderly (51, 52).

Undergoing such extensive treatment as with bimaxillary implant-supported fixed prostheses is overwhelming and, for many patients, a subject of many questions. The most common question asked by patients is if they will be able to eat normally. More specifically, illustrated by the cover of this book, and probably the most common, is if the new dentition will allow them to bite into an apple. In this aspect, these questions are the ultimate measure of **quality of life (QoL).** However, the definition of QoL has always been a subject of debate and theories in the philosophical arena. Also, disease and health are vague and could be more specific and easier to define and quantify in many aspects. Over the years, three approaches have greatly impacted those aspects: the naturalist, the holistic and the normative and constructive approaches.

The naturalist theory, including the biostatistical approach by Boorse, defines disease as biologically natural for all human beings without judging if it is good or bad. A disease lowers the probability of survival and reproduction and interferes with the performance of some natural functions which is not the nature of the species (53).

The holistic theory by Nordenfelt applies to the whole person and the individual's QoL. The analytical perspective of this theory breaks the organism into parts and analyses these parts and structures and their function. The holistic perspective considers the whole person's capacities and abilities with particular goals as part of a particular environment (54).

The normative and constructive approach believes health is based on values and norms. Medicine is denied as empirical. Therefore, the disease can be normal in one society but not in another. Along this approach, **Social Normativism** is established, meaning that it is up to us as a society and not scientific investigations to classify a state as a disease (55).

This thesis is not mainly to discuss the philosophical approaches to quality of life but clearly is that edentulism would find a place for all the three approaches. There is no doubt that edentulism may be considered natural (naturalist) but still accepted in many cultures (normative) even though it has enormous effects on people (holistic).

World Health Organisation (WHO) has defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease infirmity". Further, WHO defines quality of life as "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns".

Placing the state of edentulism or treated edentulism in the light of these definitions, there would be clear difficulties in measuring masticatory function in terms of health and quality of life. Especially reaching the stage of "complete" would be vague and impossible. Such assessment depends probably on multiple factors, not at least the dental status before the introduction of dental treatment. For instance, the impact on quality of life is greater among people with poor clinical status before introducing an improving treatment (56, 57). This applies even among patients with social and economic limitations (58, 59).

Measurements of health and quality of life related to orofacial function, OHRQoL is nonetheless complex. However, various instruments have been introduced for a comprehensive assessment covering multiple factors. In the studies this thesis is based on, health and quality of life are assessed (and quantified) using established instruments.

1.6 Masticatory function and nutrition

Malnutrition is normally associated with undernutrition. Malnutrition includes even overweight, obesity and nutrient deficiencies. Particularly, older individuals are vulnerable to malnutrition, and efforts are made to obtain adequate recommendations and policies to secure good nutrition among older adults. Achieving such goals may be limited by various restraints such as economical, physical, social, cultural and educational factors (60). However, risk factors vary between different countries (61, 62) and several sequelae, such as functional decline and frailty (63-65), are related to undernutrition. Studies have indicated a correlation between malnutrition and deteriorated quality of life (66), increased healthcare costs (67, 68), increased rate of complications (69), and mortality (64, 65, 70).

Several studies have recognised a relationship between mastication and nutrition. However, multiple factors are involved in nutrition, mastication, swallowing, and digestion, as well as many risk factors in common (71).

Nutrition is considerably affected by mastication. Older individuals are often subjected to malnutrition and undernutrition (72, 73). Impairments of masticatory function among older individuals affect nutrient intake and may lead to a general deterioration of the nutritional status and health (74-76). When large pieces of food are swallowed, the bacterial flora in the oral cavity and the gastrointestinal system is disturbed, increasing the risk of pathologies (77). Poorly digested food particles may cause bacterial overgrowth in the colon, resulting in indigestion, bloating, and constipation (78). Chewing impacts the signalling in the intestines, where digestion and nutrient absorption occur (79). BMI correlates negatively with the number and the duration of chewing cycles, indicating that chewing behaviour is associated with body weight status (80). Even various anthropometric measurements and serum albumin are well-correlated with chewing ability (81). As well, differences in mastication between individuals imply differences in glycaemic responses, i.e., the blood glucose response to carbohydrate foods (82).

Mastication is a synchronised process between several elements belonging to the masticatory system. One of the main tasks is comminuting food of various textures, hardnesses, and sizes into smaller particles. Eventually, through mixing with saliva, forming a bolus to easily and safely be swallowed before entering the rest of the digestion system for further processing and nutrient absorption (32, 83). **Altering eating habits** and food choices commonly occurs among people with poor masticatory performance to compensate for the inability to chew (84). This group of people, especially older individuals, tend to eat fewer fruits and vegetables with a lower nutrients intake as a result (85). Besides, poor masticatory performance is presented among people with removable dentures. Replacing such dentures with fixed implant-supported prostheses greatly improves masticatory performance and increases intake of protein, fibre and carbohydrates (86).

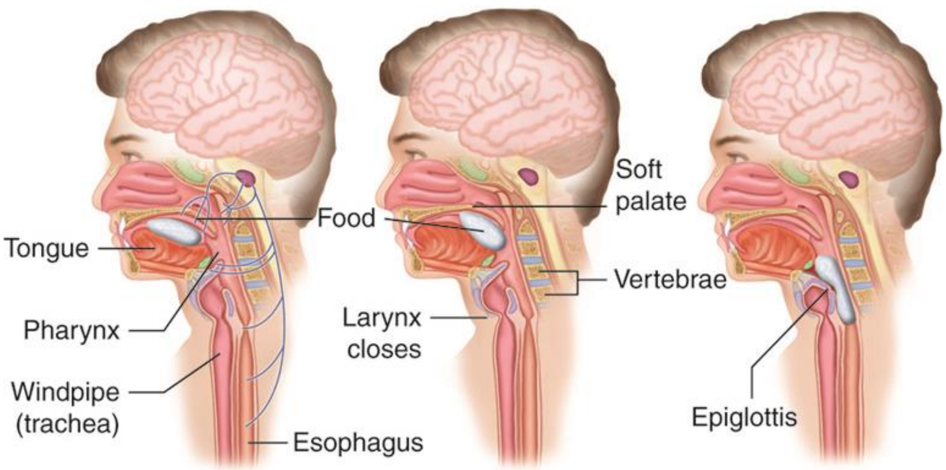


Figure 4. *Bolus formation and positioning during the swallowing process. When the food has been masticated, a bolus is formed and transported through the oral cavity* ***(the oral phase)****, the pharynx* ***(the pharyngeal phase)*** *and the esophagus* ***(the esophageal phase)****. (By Cenveo is licensed under a Creative Commons Attribution 3.0 United States (http://creativecommons.org/licenses/by/3.0/us/).*

Swallowing includes the oral, pharyngeal, and oesophageal phases, whose purpose is the transporting of food bolus into the rest of the gastrointestinal tract (Fig. 4). These accurate phases are in coordination with other structures and functions, such as chewing and respiration, crucial for safe swallowing (87). However, many factors immediately affect swallowing, such as the number of chewing cycles influencing the formation of food bolus and enhancing the swallowing process (88, 89). Chewing and food texture and size have a major effect on food transport and the swallowing procedure (90). Studies have shown that the bolus preparation is impaired in older individuals (91). Swallowing is also affected in people with removable dentures due to poor masticatory performance (92, 93). Besides, total edentulism may lead to changes in the pharynx, impairing the effective transport of the bolus (94). Despite these impairments, the number of chewing cycles before swallowing does not seem to be affected compared to people with normal masticatory performance (95). This observation suggests that large particles, too difficult to be digested, are swallowed. Prosthetic replacements are supposed to enhance mastication and, as a result, even swallowing (96).

Digestion is on various levels affected by mastication. The gastrointestinal system is influenced and thus exposed to an increased functional load due to impaired mastication (97). Besides, the gastric emptying rates are highly affected by the comminution of food (98) and chewing inefficiency is associated with irritable bowel syndrome (IBS) (99). Further, obese young individuals tend to chew fewer cycles than lean individuals before swallowing (100). Considering dental status, edentulous and partially edentulous dyspepsia patients with fewer occlusal pairs present masticatory deficiencies. Consequently, a higher degree of chronic inflammatory changes of the gastric mucosa compared to dentate controls (101). Also, obesity and digestive complaints are reported more often among patients with denture discomfort and ill-fitting dentures (71).

In sum, impairments of masticatory function have a major effect on nutrition (102). Further, poor nutritional status is associated with compromised oral functions among older adults (103). However, studies are pointing in a contradictory direction. Nevertheless, a recent systematic review concluded that pragmatic and preliminary indications support the hypothesis that mastication is a mechanical and physiological contributor to the swallowing processes in the gastrointestinal tract. Thus, even an important contributing factor related to nutrition (104). In this thesis, the masticatory performance is assumed to be optimised to a degree comparable to natural teeth. Thus, indicating that nutritional status and risk as well as masticatory performance is equivalent to people with natural dentition.

1.7 Masticatory function

A well-functioning mastication is, as mentioned above, fundamental for safe swallowing, digestion kinetics, and nutrition (105, 106). It has as well been proven that there is a mutual correlation between mastication and brain function and cognition (107-111). Therefore, the assessment of masticatory function is important and has been studied in the literature for a long time. Several variables and a wide range of terminology have been used to describe masticatory function. Among many, masticatory performance, masticatory efficiency, and masticatory ability, defined below, have been used in the literature as a measure of masticatory function. In the current thesis, the definitions below have been considered, and masticatory performance and ability are being assessed.

Masticatory performance (objective)
A measure of the comminution of food attainable under standardised conditions (112).

Masticatory efficiency (objective)
The effort required to achieve a standard degree of comminution of food (112).

Masticatory ability (subjective)
Self-assessment of masticatory function through the use of questionnaires (95, 113).

1.8 Assessment of masticatory function

1.8.1 Objective assessment

Objective assessment of masticatory function does not belong to daily clinical routine and is often associated with a series of difficulties (114). A common test used is the **food comminution test** for evaluating masticatory performance by measuring the breakdown of a test food into smaller pieces. The test food is either natural food substances such as carrots (115) and nuts (116), or artificial test substances such as silicon-based Optosil cubes (117, 118) and fuchsin beads (119). To assess masticatory performance, the samples are chewed for a predetermined number of chewing strokes and, later, usually passed through single or multiple sieves. The median particle size of the samples determines the masticatory performance. Although reliable, it is often suggested that this procedure may be time-consuming, requires specialised equipment, and is difficult to use, especially in clinical setups (120). Other substances that have gained popularity are chewing gums (121, 122) and moulding waxes (123). The tests are simple to use and rely on the ability of the participants to mix two differently coloured chewing gums or moulding waxes. It has been suggested that while the **mixing ability test** is a good method to quantify deteriorated masticatory function, it is a less sensitive test in people with relatively better masticatory performance (124). The tests also show good validity and reliability in differentiating the masticatory performance in individuals with complete and compromised dentition or individuals with complete (125, 126) and implant-supported prostheses (120).

Natural food as test specimens has the advantage of being naturally consumed and thus possible to use when normal chewing behaviour is to be assessed. However, the consistency of the food due to seasonal variations or geographical location can influence the test result (118). On the contrary, artificial substances, such as Optosil cubes, have standardised rheological properties but perhaps cannot simulate the natural chewing behaviour since one is aware that the test substance cannot be swallowed (127). Mastication aims to prepare a soft swallowable bolus which will become compromised if the person does not aim to swallow the bolus. Thus, some of the events of the masticatory process are assumed to be altered (128, 129).

Previous studies have used viscoelastic test food for assessing jaw muscle activity and adaptation to food hardness (31, 42, 43, 130-133). This type of test food would have an obvious advantage since the complexity and the physical properties of the test food (for example, hardness, size, and shape) are controlled, and the test food can be customised for the target group. Besides, a mechanically challenging test food may require larger biting forces and improved sensorimotor coordination to break down the resistant test food into sufficiently smaller particles (134). Viscoelastic food is complex and requires a high degree of sensorimotor control to breakdown. The task could be challenging for people with dental prostheses, compromised dental status, and frail older individuals. Therefore, it could be a good test to evaluate chewing difficulties, especially in older individuals with compromised dentition and decreased sensorimotor regulation.

The type of test food could influence what aspects of mastication, such as biting, crushing/grinding, mixing, or whether a combination of these, is evaluated. Therefore, it has been suggested that multiple types of specimens rather than a single type could be more useful while screening masticatory disability (135). To meet the requirement of a stadardised, diversifying, natural test food and specifically targeting the groups in the studies, two different tests were used in the studies of this thesis: a food comminution test with viscoelastic test food and a standardised and validated mixing ability test with two-coloured sugar-free chewing gum (Hue-Check Gum: Orophys GmbH Muri b.) (121, 122).

1.8.2 Subjective assessment

While the objective assessment focuses on quantifying masticatory performance, the subjective assessment considers patient-centred approaches and satisfaction after a prosthetic treatment, which is highly relevant for the degree of success (136).

The use of health measurement scales or instruments aims to identify the impact of health and healthcare to direct therapeutic efforts towards improving quality of life (137). Health measurement scales are generally classified into three types: generic, disease-specific and organ-specific (138).

Generic instruments are intended for general use regardless of disease or condition. These instruments are used for assessing the effect of illness or disease on different domains of the overall functioning or health-related QoL. An indirect assumption that poor health indicates poorer QoL is made. A weakness related to generic instruments is that different people may react differently to similar levels of impairment (138). Besides, the broad approach may reduce responsiveness to the effects of various treatments (139). The advantages of generic instruments are their ability to find unexpected effects of treatments and make comparisons between patient groups (137). The most common generic instruments are Sickness Impact Profile (SIP), Nottingham Health Profile (NHP), Medical Outcomes Study 36-Item Short Form (SF-36) and EuroQoL (EQ-5D).

Disease-specific is used to evaluate the effects of one single disease or condition. The advantage is increased sensitivity in detecting differences between the results of treatments in, for instance, clinical trials (138). Since only relevant items and questions are included, patient burden, acceptability, and responsiveness increase (137, 139). However, the possibility of a comprehensive and comparable patient or disease group assessment is reduced (137). Many disease-specific instruments have been developed. Among many, the European Organization for Research and Treatment of Cancer (QLQ-C30) and Functional Assessment of Cancer Therapy – General (FACT-G) (139). To assess oral disease and conditions, several instruments have been developed. General Oral Health Assessment Index (GOHAI) (140), Dental Impact Profile (DIP) (141), and Oral Health Impact Profile (OHIP) (142), are a few examples.

Organ-specific focuses on the functional impact of a diseased organ or domain independent of the causative disease (138). One of those instruments is Hospital Anxiety and Depression Scale (HADS) (138). For evaluations in the dental field, Mandibular Functional Impairments Questionnaire (MFIQ) (143) and Jaw Functional Limitation Scale (JFLS) (144), etc. are used.

One would expect a strong correlation between satisfaction and performance, but such a correlation is weak regarding prosthetic treatments (145, 146). Whether this applies to treatment with bimaxillary implant-supported prostheses is not clear. In this thesis, in particular Study II, was intended to attain a comprehensive evaluation of masticatory function, focusing on jaw function and quality of life. Therefore, organ- and disease-specific instruments were considered adequate for the purpose. Besides, the validity and reliability of the translated versions into Swedish were considered important. Out of several instruments, JFLS-20, and OHIP-49, translated to Swedish, considered comprehensive, simple to complete, and with good reliability and validity, were chosen.

1.9 Assessment of nutrition

The nutritional assessment aims to identify deficiency states, evaluate the nutritional qualities of diets and habits, and predict effects on health and the human body. In general, the assessment of nutrition employs four different categories (147, 148):

Anthropometric assessment relies on physical dimensions such as height, weight, and gross composition of an individual’s body. Those measurements are compared with previous measurements of the individual and with standard values specific for gender and age. Through these measurements and comparisons, the progress of growth, undernutrition, overnutrition, and changes in body composition over time are detected.

Clinical assessment is based on physical examination by a qualified observer and symptoms stated by the patient. A medical, personal, social, and nutritional history and signs of malnutrition are obtained. This assessment category includes self-reported dietary records in the range of one to several days.

Biochemical assessment focuses on the internal processes of the body. The purpose is to assess nutritional status, imbalance, deficiencies, and toxicity. The most common way of doing this is through blood and urine samples. Analysing values of nutrients, enzymes, and metabolites and comparing them to normal values, reveals signs of malnutrition.

Sociologic assessment predicting nutritional status by analysing information not directly related to nutrition but known to affect nutritional status. Such factors are socioeconomic status, food habits, food preparation, quality of drinking water, family structure etc.

In this thesis, particularly Study III, the purpose was to, in a simplified manner, assess nutritional status and eating habits and to identify nutritional risks. Focus was set on conducting a comprehensive assessment and obtaining data for identifying nutritional risks and malnutrition. Hence, two questionnaires, MNA® and SCREEN II, including anthropometric, clinical, and sociological assessments were used. The questionnaires have been translated into Swedish and are considered easy to complete. A three-day dietary record to chart eating habits was also used.

2 Research aims

2.1 General aims

The thesis aims to evaluate masticatory function and nutrition in edentulous people treated with bimaxillary implant-supported fixed prostheses. Overall, the research outcome will help identify functional impairments and nutritional risks and facilitate the development of clinical routines for optimum restoration of masticatory function after oral rehabilitation procedures.

2.2 Specific aims

Study I

To evaluate the masticatory performance of individuals with bimaxillary implant-supported fixed prostheses compared to people with natural teeth using a simplified and less time-consuming food comminution test and a mixing ability test.

Study II

To analyse the subjective and objective measures of masticatory function in people treated with bimaxillary implant-supported fixed prostheses and to study the correlation between those measures.

Study III

To evaluate nutritional status, nutritional risk, and eating habits in people treated with bimaxillary implant-supported fixed prostheses compared to people with natural dentitions.

3 Materials and methods

3.1 Recruitment of participants

All three studies were conducted according to the Declaration of Helsinki II regulations, and approval was obtained by the Swedish Ethical Review Authority in Stockholm, Sweden (2018/1963-31). All participants were given thorough information about the study and the method of data collection before their participation. The participants were recruited when their agreement on verbal and written informed consent for their participation was obtained.

The experimental groups were treated according to a two-stage protocol. If teeth were to be extracted, a healing period of a minimum of six months in the maxilla and three months in the mandible was assured before proceeding with the first stage, installing the implants. When the first stage was completed, the implants were allowed to heal, covered by the mucosa for six months in the maxilla and three months in the mandible. The purpose of the second stage was to expose the implants and connect abutments with adequate height. Later, the prosthetic procedures started, resulting in screw-retained metal-acrylic implant-supported fixed bridges of twelve teeth per arch (Fig. 5).

All participants of the experimental groups were recruited from GHP Specialisttandläkarna, Nacka, Sweden. At the clinic, all implant treatments are registered and filed in a database built in the Filemaker software (Claris Filemaker). All treated patients are followed up after one year and later for intervals of five years after completion of the treatment. Complications such as loss of implants, progressive bone destruction, fractures etc., are registered. The database search engine extracted edentulous patients aged 55–80 years and treated with bimaxillary implant-supported fixed prostheses. Those who were due for regular follow-up in the following two years were included. Participants whose prostheses had been in function for at least a year and not subject to any complications, became candidates for the study. The main researcher (George Homsi) made the first contact over the phone with all candidates who were informed about the study's objectives. A written consent form was mailed if they declared they were satisfied with the treatment and approved the study.

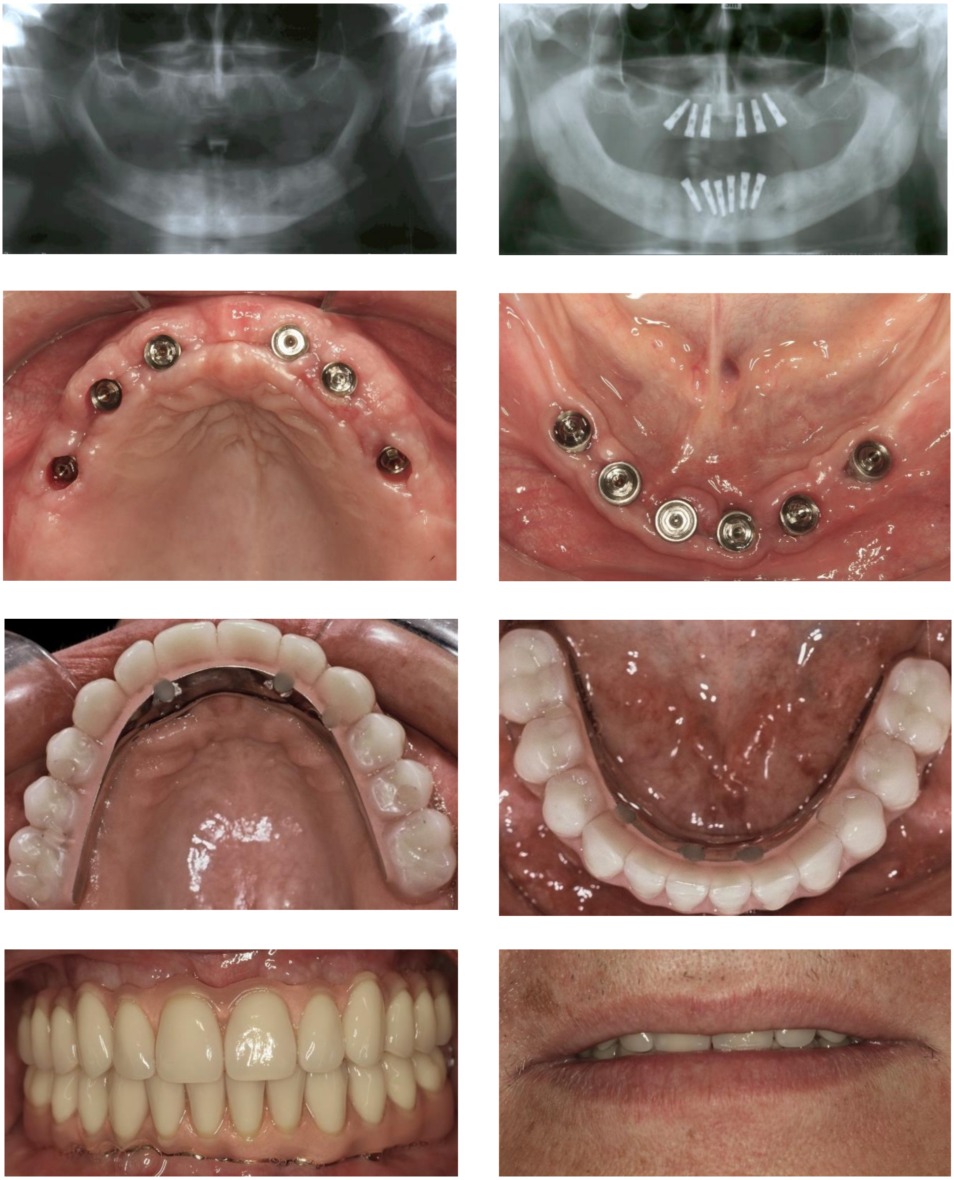


Figure 5. *An edentulous patient treated with bimaxillary implant-supported fixed prostheses in a 2-stage procedure on abutment level. After a healing period of 3 – 6 months after the installation of the implants, abutments are connected. The screw-retained metal-acrylic implant-supported fixed bridges of 12 teeth per arch is connected after 4-5 weeks.*

For the explorative phase of Study I, the participants were young, healthy adults. The volunteers presented 28 natural teeth and were recruited only if they were free from functional or gross malocclusions.

The control groups' participants are recall patients at Tandvården Sergel, Praktikertjänst, Stockholm. Patients in the age of 55–80 with natural teeth and without the presence of implants, bridges and/or removable dentures were included. Accordingly, the qualified patients were contacted through a phone call. When accepted, they were asked to sign the consent form sent by mail.

3.2 Study Participants and Methods

Study I

An experimental group with bimaxillary implant-supported fixed prostheses and a dentate control group consisting of 18 participants each were included according to the criteria mentioned above. Besides, 22 healthy volunteers aged 19-39 years were recruited for the explorative phase of Study I. All participants in the explorative phase presented 28 teeth and were free from functional or gross malocclusions or ongoing or previous endodontic/prosthetic (crowns/ bridges/ implants) treatments. Besides, all participants in all three groups were in good general health without a history of systemic, chronic, or neurological disease affecting the masticatory system. In addition, none reported orofacial pain or temporomandibular disorders. In each of the experimental and control groups, the participants were included according to the criteria mentioned above. During the study, two different tests were performed: **A food comminution test and a chewing ability test.** Both tests aimed to assess the masticatory performance in the groups and further make the comparison between the experimental and control groups.

Study II

An experimental group with bimaxillary implant-supported fixed prostheses and a control group with natural dentitions were recruited for this study. Each group included 25 participants according to the inclusion criteria listed above. An objective and a subjective evaluation of the masticatory function were performed. A food comminution and a chewing ability test were performed to obtain the objective measures. For the subjective assessment, two instruments were used: JFLS-20 and OHIP-49.

Study III

Participants in this study were a total of 50, divided into an experimental group with bimaxillary implant-supported fixed prostheses and an equal dentate control group. The focus in this study was assessing nutritional status and risk using MNA® and SCREEN II, besides identifying eating habits through a three-day dietary record.

3.3 Tests and instruments

3.3.1 Food comminution test

The test aims to obtain various parameters for assessment of masticatory performance using a standardised hard-viscoelastic test food prepared in the laboratory. Gelatine of

250 bloom (41.5 g) is mixed with glucose (132 g), sugar (111 g), water (84 g), and citric acid. The gelatinous mixture is prepared in an 80 °C water bath for four hours and coloured with food colour. The mixtures are then poured into cylindrical Plexiglas models (10 mm high and 20 mm in diameter) and kept for 24 hours. Later the test food was placed in an airtight box for 72 hours before usage (42, 130, 133). To ensure the mechanical properties of the test food, ten samples from each batch have previously been tested in a universal testing machine (AG-G, Shimadzu Co., Kyoto, Japan). A uniaxial compression of 5 mm at 50 mm/min was applied while the forces were measured at a rate of 250 samples/s. The gauged hardness of about 130 kPa is assured before proceeding with the use of test food (Fig. 6). Besides the test food, Petri dishes painted with a white background, a mobile phone camera at a resolution of 4032x3024 pixels (iPhone XR; Apple Inc) fixed on a tripod, and a software (ImageJ; Image Processing and Analysis in Java) are required for the test.

Figure 6. *Preparation of the test food in the laboratory. The samples have previously been tested to assure a hardness of ~ 130 kPa before approved for use in the studies.*

3.3.2 Mixing ability test

This test is used for assessing the mixing ability as an indicator of masticatory performance. It requires an 8x20x12 mm two-coloured sugar-free chewing gum (Hue-Check Gum: Orophys GmbH Muri b.) included in a standardised and validated test (121, 122). Besides the chewing gums, a custom guide template, cellophane papers, a flatbed scanner (Epson Perfection V700 Scanner; Epson) and an analysing software (ViewGum; dHAL Software) are needed for the test (Fig. 7).

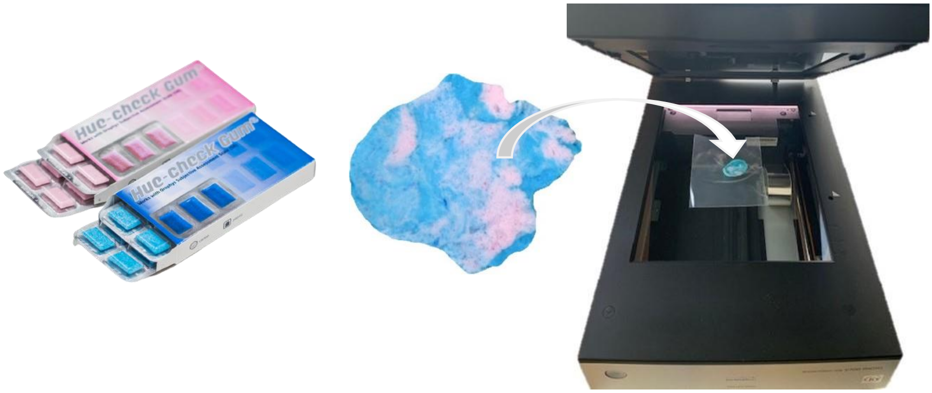


Figure 7. *The two-coloured sugar-free chewing gum* (Hue-Check Gum: Orophys GmbH Muri b.) *used for the chewing ability test and later placed in cellophane paper and scanned in the flatbed scanner* (Epson Perfection V700 Scanner; Epson). Partially modified from figure from Orophys GmbH Muri b.

3.3.3 JFLS-20

Jaw Functional Limitation Scale is an organ-specific instrument for evaluating the self-reported status of the masticatory system. The reliability and validity of the Swedish version have been proven to be good (144, 149, 150). It comprises 20 items aimed at measuring the functional limitation of the masticatory system. Each item representing a limitation is rated by the participants on a scale of 0-10, where "0" equals no limitation and "10" corresponds to extreme limitation (Appendix 11.1).

3.3.4 OHIP-49

Oral Health Impact Profile is an instrument for assessing and improving oral health-related quality of life (QHRQoL) (142). It is used to evaluate the effects of organ-related conditions or diseases on both jaw function and QHRQoL. The Swedish version has been proven to have excellent reliability and acceptable validity (151). Possible response options are 0=never, 1=hardly ever, 2=occasionally, 3=fairly often or 4=very often (Appendix 11.2).

3.3.5 MNA®

Mini Nutritional Assessment is established in countries worldwide, including Sweden, to evaluate nutritional status. Mainly it is used among the elderly in homes, clinics, hospitals, and nursing homes and can be completed quite effectively (152, 153). Multiple measurements are included. **Anthropometric measurements** (weight, height, and weight loss) for detecting body composition and weight loss, **Global assessment** (lifestyle, medication, and mobility) for identifying risk factors for malnutrition, such as home dwelling and medication, **Dietary questionnaire** (dietary habits such as type of food, number of meals, fluid intake etc.), and **subjective assessment** (self-perception of health and nutrition). (Appendix 11.3).

3.3.6 SCREEN II

Seniors in the Community: Risk Evaluation of Eating and Nutrition comprises 14 questions/items divided into sub-questions. Information such as weight loss, food intake and risk factors for malnutrition are obtained. The items have different ranges, typically 0–4 (good–very poor) (Appendix 11.4).

3.3.7 Dietary records

A prospective and open-ended 3-day record includes food records for two weekdays and one of the weekend days. All meals, times and ingredients of foods and drinks are noted. Besides, a rough estimation of amounts in grams, tablespoons, and decilitres is obtained.

3.4 Experimental Protocols and Procedures

3.4.1 Study I

Food comminution test

During the explorative phase, the participants were asked to perform the food comminution test with five pieces of hard-viscoelastic test food. The participants were asked to spit out the particles into a Petri dish after four, eight, twelve, sixteen and twenty chewing cycles (Fig. 8).

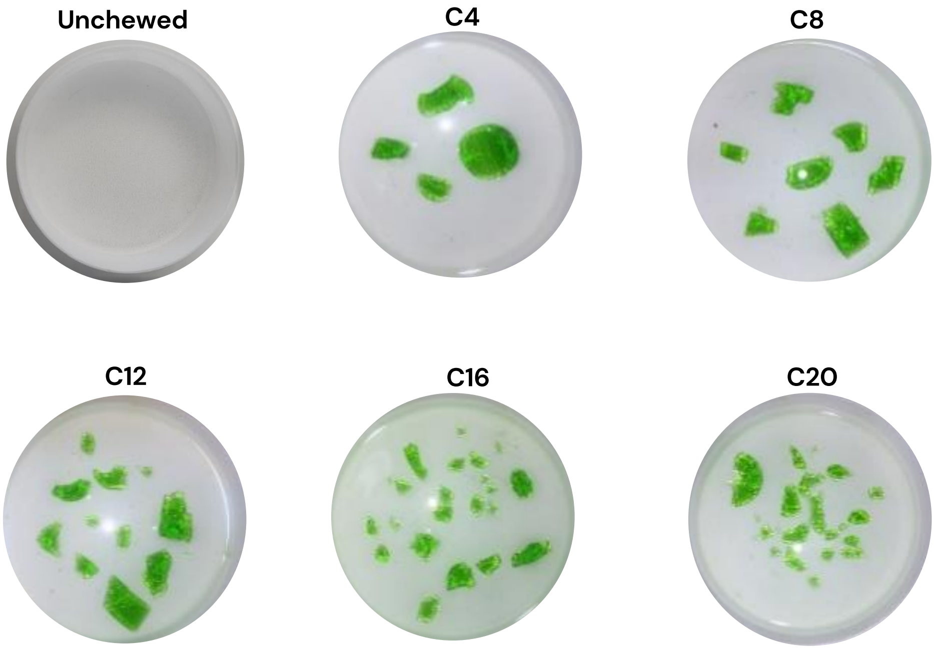


Figure 8. *The explorative phase of Study I. Samples obtained after 4, 8, 12, 16, and 20 chewing cycles.*

During the comparative phase, the participants ate the first piece entirely, and the trial was video recorded. During the second and third trials, the participants were interrupted after ten chewing cycles and asked to spit out the remnants into a Petri dish (Fig. 9).

Chewing ability test

The same protocol was used for both the explorative and the comparative phases during this study. According to the standard protocol, the two-colour chewing gum was wetted with water and gently put together. The participants were then asked to put the chewing gums into their mouths and chew on their preferred side. After twenty chewing cycles, the chewing gum was collected after the participants were interrupted and asked to spit it out on a cellophane paper.

3.4.2 Study II

Objective assessment

The food comminution test was applied per the protocol of the first study's comparative phase. The mixing ability test was also performed to evaluate the masticatory performance in the experimental and control groups.

Subjective assessment

Both questionnaires, JFLS-20 and OHIP-49, were sent to the participants by mail five weeks before the experimental session of the study. On the day of the visit, the participants were allowed to ask questions to clarify any uncertainties related to the questionnaires. The questionnaires were collected and filed under each participant's research records.

3.4.3 Study III

Nutritional assessment

The questionnaires of MNA® and SCREEN II and a guide for filling in the dietary record were delivered by mail. The participants were given five weeks to return the filled questionnaires and the completed dietary records. Any questions were answered to ensure that all details were appropriately filled in. The questionnaires were collected and filed under each participant's research record.

3.5 Data analysis

3.5.1 Food comminution test

In the Petri dish containing the remnants of the test food, 30 ml of water was added to the obtained particles to separate the particles easily and gently without causing any damage. With the help of the mobile phone camera mounted on the tripod, a photography at 11 cm from the specimen was taken under standardised lighting conditions. The image was transferred to ImageJ software (Image Processing and Analysing in Java) for further processing and analysis. The number and total area of the particles were obtained and considered as a measure of the masticatory performance. A higher number and a larger area indicate better masticatory performance. The entire session of the food comminutions test was video recorded. Specifically, the recording was later reviewed during the first trial in the comparative phase of the first study. Analysis of the swallowing events allowed obtaining the number of cycles and duration needed for the first and final swallow (Fig. 9).

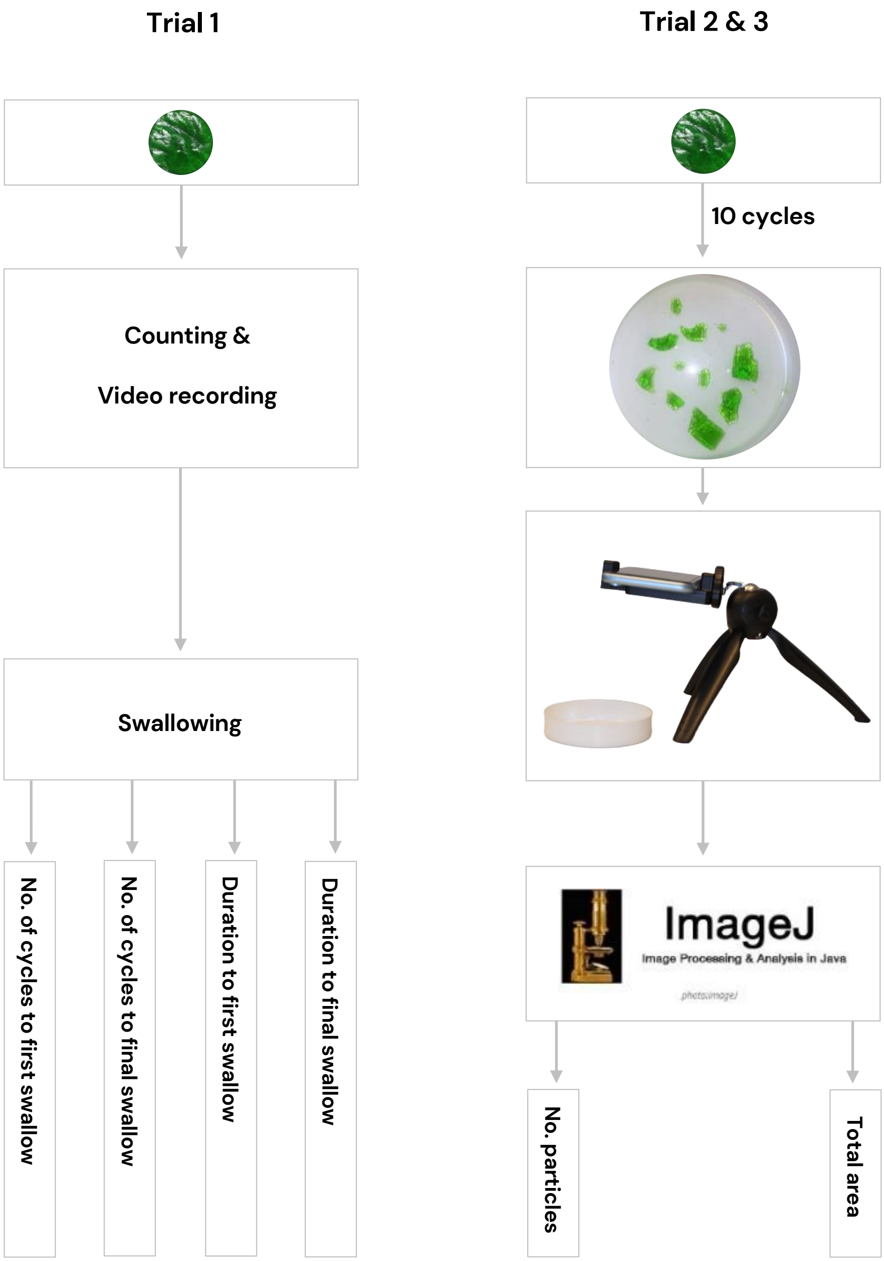


Figure 9. *The food comminution test. The procedure of obtaining values representing duration and number of cycles to the first and final swallowing. Number of particles and total area is obtained as a measure of masticatory performance.*

3.5.2 Chewing ability test

After being spat out, the chewing gum enclosed in the cellophane paper was flattened in the template guide to a wafer of a thickness of 1 mm. Later, the specimen was scanned from both sides in the flatbed scanner with a resolution of three hundred dots per inch and 24-bit colour depth. The two obtained images were saved in the Joint Photographic Experts Group format (JPG) for further analysis in the computer program ViewGum (ViewGum; dHAL Software). In the software, the images were transformed into hue saturation intensity colour space, obtaining the variance of Hue (VOH) (Fig. 10). A larger VOH indicates poorer mixing ability.

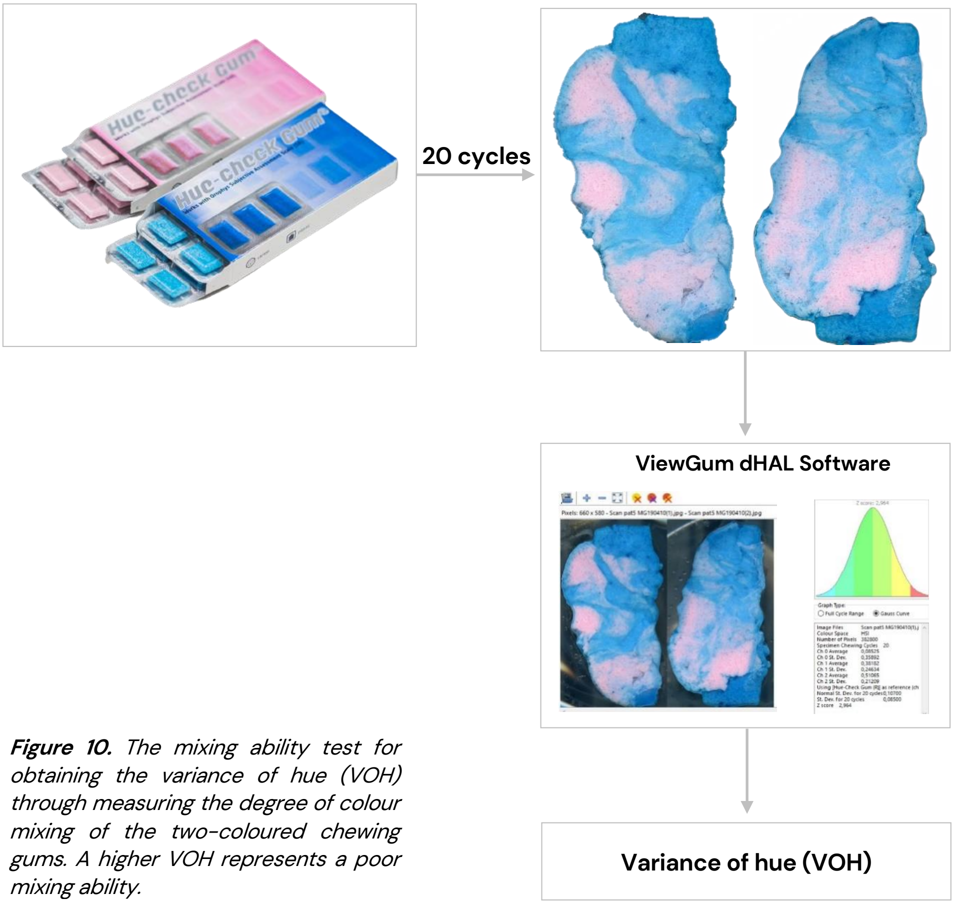


Figure 10. *The mixing ability test for obtaining the variance of hue (VOH) through measuring the degree of colour mixing of the two-coloured chewing gums. A higher VOH represents a poor mixing ability.*

3.5.3 JFLS-20

The items are grouped into three conducts representing mastication (questions 1-6), vertical mobility questions 7-10) and verbal and non-verbal communication limitations (questions 11-20). The mean and sum of each of the three conducts and the sum of the means representing the total score were calculated. A maximum of 200 units for the total score can be obtained. A higher score indicates an increased functional limitation (Table 1).

Table 1. *The conducts and maximum scores of JFLS-20*

Jaw Functional Limitation Scale (JFLS-20)	Questions	Maximum score
Mastication	1-6	60
Vertical jaw mobility	7-10	40
Verbal & emotional com.	11-20	100
Total Score	1-20	200

3.5.4 OHIP-49

The forty-nine questions are subdivided into seven subdomains comprising a group of questions representing functional limitation (questions 1-9), physical pain (questions 10-18), psychological discomfort (questions 19-23), physical disability (questions 24-32), psychological disability (questions 33-38), social disability (questions 39-43), and handicap (questions 44-49). The mean and sum were calculated for each of the subdomains. Besides, a total score of the entire questionnaire was calculated. A higher score indicates a poorer quality of life (Table 2).

Table 2. *The subdomains and maximum scores of OHIP-49*

Oral Health Impact Profile (OHIP-49)	Questions	Maximum score
Functional limitation	1-9	36
Physical pain	10-18	36
Psychological discomfort	19-23	20
Physical disability	24-32	36
Psychological disability	33-38	24
Social disability	39-43	20
Handicap	44-49	24
Total score	1-49	196

3.5.5 MNA®

In the related study, only anthropometric measurement (weight, height, and weight loss) and global assessment (six questions related to lifestyle, medication, and mobility) were used. Thus, obtaining Body Mass Index (BMI) and a screening result in the range of 7 – 14. For the latter, a score of 0 – 7 indicates malnutrition, 8 – 11 risk malnutrition, and 12 – 14 normal nutritional status. For the BMI, a score <18.5 represents underweight, 18.5 - <25 healthy weight, 25 - <30 overweight and ≥30 obesity (Table 3).

3.5.6 SCREEN II

Compiling the scores of the questions implies a total score in the range of 0–64. A lower score indicates an increased risk of malnutrition. Thus, a score of <50 indicates a high-risk nutritional deficiency, while 50–53 a moderate-risk nutritional deficiency and >53 indicates a low-risk nutritional deficiency (Table 3).

Table 3. *The interpretation of the scores of MNA®, BMI and SCREEN II indicating nutritional status and risk.*

MNA®	
12 – 14	Normal nutritional status
8 – 11	At risk of malnutrition
0 – 7	Malnourished
BMI	
<18.5	Underweight
18.5 – <25	Healthy weight
25 – <30	Overweight
≥30	Obesity
SCREEN II	
<50	High-risk nutritional deficiency
50 – 53	Moderate risk nutritional deficiency
≥54	Low-risk nutritional deficiency

3.5.7 Dietary records

Parameters obtained from dietary records are to evaluate eating habits and choice of food. The solid food intake, i.e., food items other than fluids, is categorised into six food groups: vegetables, fruits, meat/fish, dairy, snacks, and starches (154). The stated time of the meal is considered an indicator of an individual meal. The total number of food items (excluding the fluids) was counted for each participant, and the percentage of each food group was calculated.

3.6 Statistics

All data were analysed in statistical software programs (IBM SPSS Statistics for Windows, v25.0; Armonk, NY: IBM Corp).

3.6.1 Study I

Explorative phase

The data were subjected to linear regression analysis. The Shapiro-Wilk test was applied to assess normality and logarithmic transformation was done whenever data were not normally distributed. All data from all participants and sessions were then subjected to a 1-way repeated measures analysis of variance (ANOVA).

Comparative phase

Shapiro-Wilk test was used for assessing normality. The normally distributed data were analysed with an independent sample *t*-test. For the statistical analysis of the differences between the groups in VOH, the number of masticatory cycles, and duration, to the first and final swallow, the Mann-Whitney U test (α = .05) was used.

3.6.2 Study II

G*Power version 3.1.9.7 was used to calculate power and sample size and determine the number of participants required to test the study hypothesis. Only data related to the total area were normally distributed when subjected to the Shapiro-Wilk test. Thus, these data were analysed with an unpaired *t*-test to investigate the differences between the experimental and the control group. All skewed data were analysed with the Mann-Whitney U test (α = .05). The correlation analysis was performed using Spearman's rank correlation coefficient.

3.6.3 Study III

For the assumption of normality, histogram plots and Shapiro-Wilk tests were used. Normally distributed data such as food categories, were analysed and compared between the groups with the parametric student *t*-test. All skewed data were subjected to the non-parametric Mann-Whitney U test (α = .05).

4 Results

All participants in the three studies successfully performed the experimental parts of the studies and completed the questionnaires. Two dietary records in the experimental group were not completed and thus not included in the analysis.

4.1 Study I

Explorative phase

The number of chewing cycles correlated positively with the number of particles (r = 0.873, $P < .001$) and total area (r = 0.744, $P < .001$), implying an increasing number of particles and total area with the increased number of chewing cycles. Further analysis showed a significant increase in number of particles during all five trials ($P < .011$) except between C16 and C20 ($P < 0.732$) (Fig. 11A). A significant increase ($P < .014$) of total area ceased between C12 and C16 ($P = 0.983$) and C16 and C20 ($P = 0.086$) (Fig. 11B).

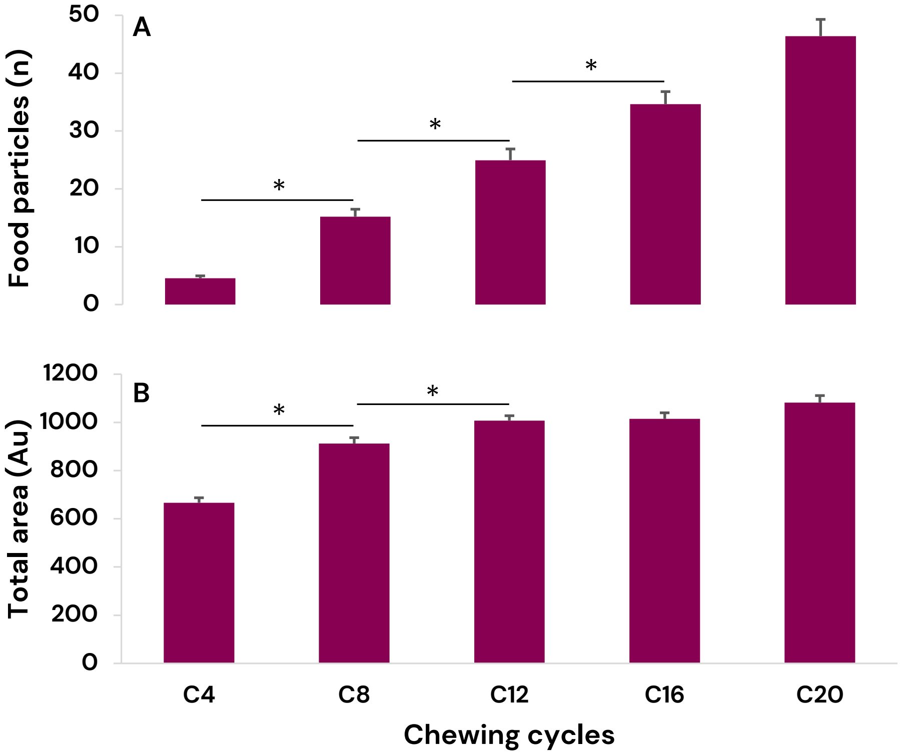


Figure 11. A. *Mean and standard error of mean (SEM) of food particles.* ***B.*** *Mean and standard error of mean (SEM) of total area of food particles. Values obtained during food comminution test with hard viscoelastic test food. *Significant differences (P<.05).*

Comparative phase

From the first trial of this phase, the mean number of chewing cycles and duration of the first and final swallow for both groups, were calculated. The groups exhibited no significant differences in the number of chewing cycles to either the first (U = 155, *P* = 0.824) or the final swallow (U = 129, *P* = 0.295), between the two groups. Neither was a significant difference detected regarding the duration of chewing to the first (U = 143, *P* = 0.557) or the final swallow (U = 135, *P* = 0.401).

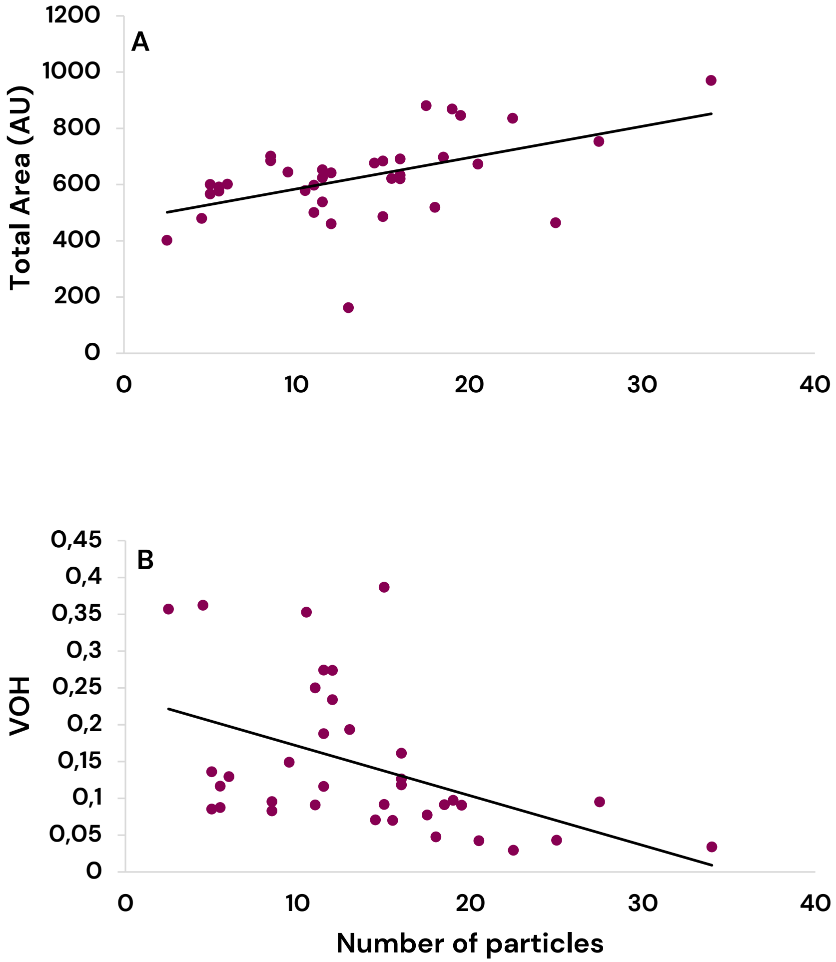


Figure 12. *The correlation analyses obtained from the explorative phase* ***A.*** *between the number of particles and total area and* ***B.*** *between the number of particles and VOH.*

An overall positive correlation was found between the number of particles and total area (r = 0.51, $P < .005$), i.e., an increasing total area with an increased number of particles (Fig.

12A). Also, a negative correlation between number of particles and VOH (r = -0.46, *P* = .005) was detected and thus indicating an increased color mixing (Fig. 12B).

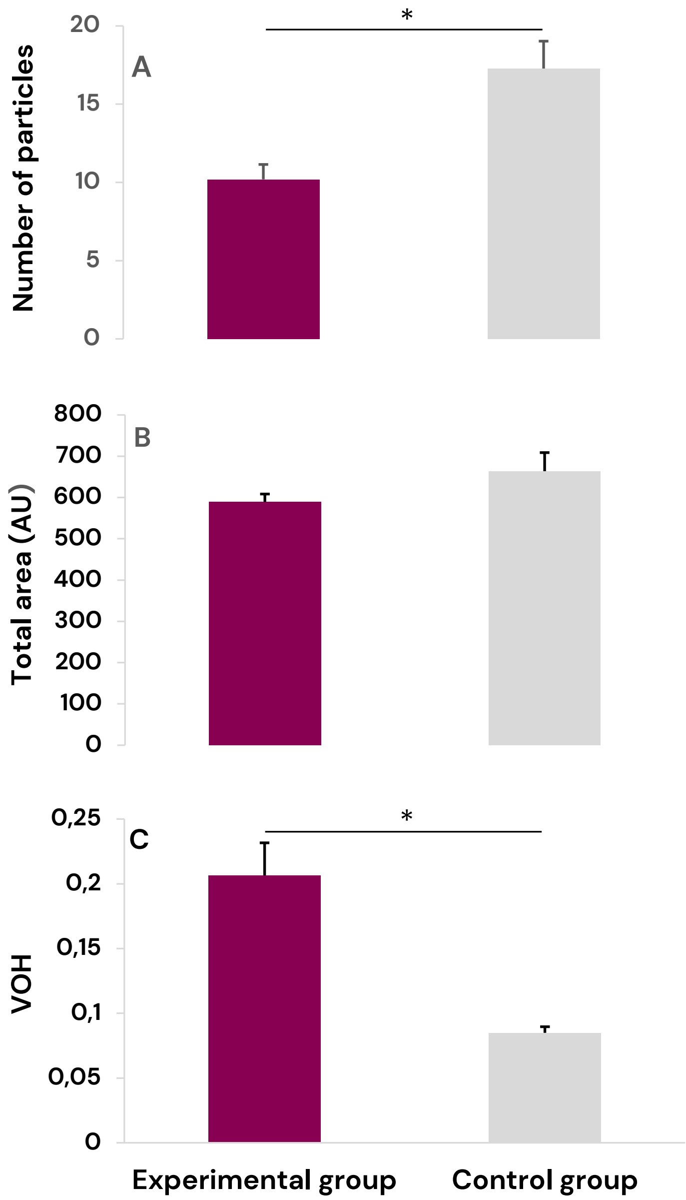


Figure 13. *Mean and standard error of mean (SEM) for experimental and control group.* ***A.*** *Number of particles, from the food comminution test.* ***B.*** *Total area of food particles, from the food comminution test* ***C.*** *Variance of hue (VOH) values from the mixing ability test. *Significant differences (P < .05)*

The mean of the average number of particles and total area obtained in the second and third trials were analysed and compared between the experimental and the control groups. The experimental group exhibited a significantly lower number of particles than the control group (t (34) = -3.554, *P* <.001) (Fig. 13A), indicating an inferior masticatory performance in the comminution test. Similarly, the mixing ability test exposed the differences between the groups with significantly higher VOH in the experimental group compared to the control group (U = 46, *P* < .001) (Fig. 13C), indicating an inferior mixing ability. However, a difference in the total area between the two groups could not be detected (t (34) = -1.552, *P* = 0.137) (Fig. 13B).

4.2 Study II

Objective assessment

Food comminution test

As in Study I, no significant difference between the groups could be detected in the number of cycles to the first (U = 258, *P* = 0.289) and the final swallow (U=305, *P* = 0.892). No significant difference between the two groups was either found in the duration of the first (U = 259, *P* = 0.279) or the final swallow (U = 307, *P* = 0.915) (Table 4). However, a difference in masticatory performance was detected through a significantly lower number of particles in the experimental group in comparison to the control group (U = 107.5, *P* < .001) (Table 4). In addition, the experimental group exhibited a smaller total area of the comminuted particles compared to the control group (t (48) = -3.123, *P* = .003) (Table 4).

Table 4: *Objective assessment of masticatory function with food comminution and mixing ability test. Mean ± SD and P-value. * indicates a significant difference between the groups.*

	Experimental	Control	*P*-value
Number of cycles to first swallow (N)	21.8 ± 5.6	20.6 ± 6.9	0.289
Number of cycles to final swallow (N)	26.8 ± 8.1	29.2 ±13.0	0.892
Duration to first swallow (Sec)	20.3 ±7.2	18.0 ± 4.9	0.297
Duration to final swallow (Sec)	26.0 ± 9.8	27.2 ± 12.1	0.915
Number of particles (N)	10.7 ± 3.9	20.7 ± 11.5	**0.000***
Total area (AU)	580691 ±	714463 ± 198324	**0.003***
Variance of hue (VOH)	0.197 ± 0.12	0.086 ± 0.04	**0.000***

Mixing ability test

The experimental group showed significantly higher VOH compared to the control group (U=114, $P < .001$) (Table 4). Thus, the mixing ability of the experimental group is significantly inferior to the control group.

Subjective assessment

JFLS-20

About 40 % of the participants in the experimental group and 28 % of the participants in the control group reported some degree of limitation. The score of the conduct of vertical mobility was significantly higher for the experimental group (U = 236, $P = .047$). However, no significant difference was detected in the conduct of mastication (U = 256, $P = 0.194$) or verbal and emotional communication (U = 261, $P = 0.117$). Overall, there was no significant difference between the two groups in the total JFLS scores (U = 242.5, $P = 0.114$) (Table 5).

***Table 5**: Subjective assessment of masticatory function with JFLS-20. Mean ± SD and P-value. * indicates a significant difference between the groups.*

Jaw Functional Limitation Scale (JLFS-20)	Experimental	Control	*P*-value
Mastication	3.0 ± 5.3	0.9 ± 1.9	0.194
Vertical jaw mobility	1.6 ± 3.2	0.4 ± 1.3	**0.047***
Verbal & emotional com.	4.1 ± 12.4	0.5 ± 2.2	0.117
Total Score	8.7 ± 20.4	0.6 ± 5.1	0.114

***Table 6:** Subjective assessment of masticatory function with OHIP-49. Mean ± SD and P-value.*

Oral Health Impact Profile (OHIP-49)	Experimental	Control	*P*-value
Functional limitation	6.80 ± 7.8	3.2 ± 3.3	0.069
Physical pain	5.24 ± 8.3	3.2 ± 3.8	0.470
Psychological discomfort	2.08 ± 4.5	1.8 ± 3.5	0.966
Physical disability	4.28 ± 8.0	1.6 ± 2.6	0.102
Psychological disability	2.04 ± 5.2	2.3 ± 3.3	0.158
Social disability	1.52 ± 4.2	1.3 ± 1.8	0.440
Handicap	2.20 ± 5.1	1.3 ± 2.8	0.670
Total score	24.16 ± 40.7	14.4 ± 18.2	0.312

OHIP-49

The scores of the seven subdomains and the total score of OHIP-49 revealed no significant differences between the groups. Thus, the self-reported dysfunction, discomfort and disability attributed to oral health were not affected in people treated with bimaxillary implant-supported prostheses compared to people with natural teeth (Table 6).

Correlation between objective and subjective measures

Certain significant positive correlations between the objective and subjective measures could be found. Specifically, in the control group, significant positive correlations were detected between the number of particles and the total score of JFLS-20 (r = 0.512, *P* = .009), the conduct of mastication (r = 0.514, *P* = .009), mobility (r = 0.437, *P* = .029), and verbal and emotional communication (r = 0.432, *P* = .031). Besides, the total area correlated positively and significantly to the total score of JFLS-20 (r = 0.524, *P* = .007), mastication (r = 0.525, *P* = .007), mobility (r = 0.438, *P* = .029), and verbal and emotional communication (r = 0.451, *P* = .024). However, there was no such correlation in the experimental group. Further, there was no significant correlation between the VOH values from the mixing ability test and any of the conducts of the JLFS-20 in either the experimental or the control group.

The results of the correlation analysis of OHIP-49 scores detected a significant positive correlation between total area and the subdomains of psychological discomfort (r = 0.43, *P* = 0.033), psychological disability (r= 0.46, *P* = 0.020), and social disability (r = 0.48, *P* = 0.015) in the experimental group. However, no correlation was found with any of the other subdomains or between the number of particles or VOH and any of the subdomains for any of the groups.

4.3 Study III

MNA®

Two (8 %) of the participants in the experimental group and one (4 %) in the control group were at risk of malnutrition. Otherwise, all other participants were in the range of normal nutritional status but still had a significantly higher MNA® score for the experimental group (U = 204.5, *P* = 0.022). The mean MNA® score for the experimental group was 13.3 ± 1.3 and 12.9 ± 1.1 for the control group (Table 7).

None of the participants had a BMI in the range of underweight. Eight (32 %) participants in the experimental group and three (12 %) were in the range of obesity. Besides, eight (32 %) participants in the experimental group and 5 (20 %) participants in the control group were within the overweight range (Table 8). However, the results showed that participants in the experimental group (27.6 ± 4.1) tended to have a significantly higher BMI (U = 168.5, *P* = 0.005) than the control group (24.7 ± 4.2). Overall, the figures revealed that the experimental group participants were overweighted, while the participants in the control group were in the healthy weight range.

Table 7. *The results of the analysis of the scores of MNA®. The number and percentage of participants in each of the groups classified by risk of malnutrition.*

MNA®		Experimental (%)	Control (%)
12 - 14	Normal nutritional status	92	96
8 - 11	At risk of malnutrition	8	4
0 - 7	Malnourished	0	0

Table 8. *The results of the analysis of the scores of BMI scores obtained from MNA®.*

SCREEN II

A mean score of 48.5 in the experimental group indicated a high risk of malnutrition, compared to 52.7 indicating a moderate risk in the control group. The difference is significant (U = 183, *P* = 0.012). A closer analysis revealed a high-risk nutritional deficiency among fourteen (56 %) participants in the experimental group and five (20 %) in the control group. Further, three (12 %) participants in the experimental group and eight (32 %) in the control group were in the range of moderate-risk nutritional deficiency (Table 9).

Table 9. *The results of the analysis of the scores of SCREEN II. The number and percentage of participants in each of the groups classified by risk of nutritional deficiency.*

SCREEN II		Experimental (%)	Control (%)
<50	High-risk nutritional	56	20
50 - 53	Moderate risk nutritional	12	32
≥54	Low-risk nutritional	32	48

Dietary records

The number of food items consumed during the three days were categorised into six food groups based on the food preference, and percentage of each category was calculated. The percentage of food items for each food group category was then compared between the groups. The results of the dietary records showed that the participants in the experimental group significantly consumed fewer meals (*P* = 0.006) (Fig. 14A) and a lesser variety of food (P < 0.001) than the control group during the three days (Fig. 14B).

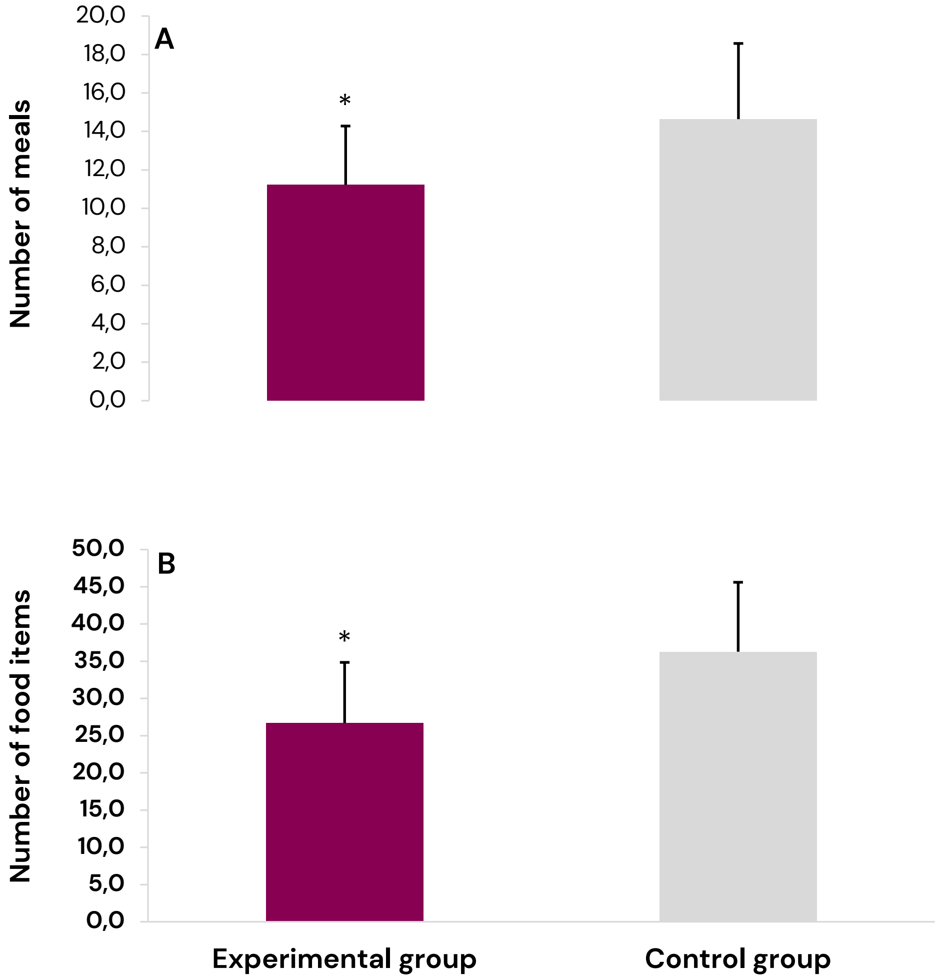


Figure 14. *Results obtained by the 3-day dietary record. Mean and standard deviation of the* ***A.*** *number of meals and the* ***B.*** *variety of food from the three-day dietary records. *Significant differences (P < 0.05). Error bars. 95 % CI.*

The experimental group consumed significantly more meat/fish than the control group (*P* = 0.025). A significantly lower number of fruits than the control group (*P* = 0.011) (Fig. 15). No differences in the consumption of vegetables (*P* = 0.918), dairy (*P* = 0.274), snacks (*P* = 0.715), or starches (*P* = 0.931) were found between the groups (Fig. 15).

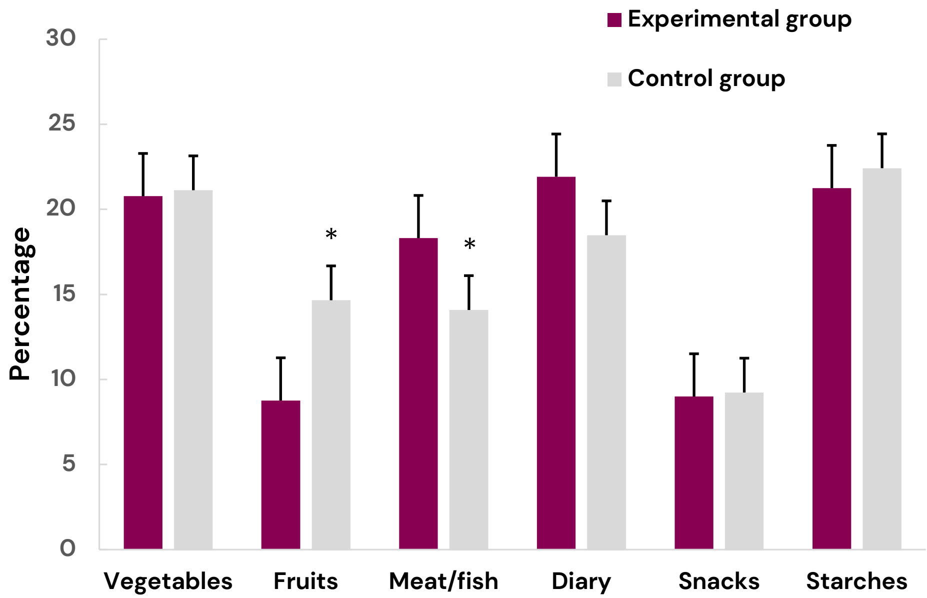


Figure 15. *Food preferences including the six food categories obtained from the three-day dietary record, presented as percentage of the total number of meals in each of the experimental and control group. Mean and standard deviation. *Significant differences(P < 0.05). Error bars 95 % CI.*

5 Discussion

Dental implants have become a natural choice of tooth replacement for many professionals and patients worldwide thanks to the important role of teeth in oral functions, health, and quality of life. Especially total edentulous patients have largely benefited from implants and bimaxillary implant-supported fixed prostheses, considered state-of-the-art. Problems such as denture retention and dysfunctions related to conventional removable prostheses have been eliminated through replacements with completely implant-retained bridges that aid in better function, anatomy, and aesthetics. The absence of teeth may, however, impact the treatment outcome. For instance, studies have shown altered oral sensorimotor control, an important aspect discussed in the introduction of this thesis.

While dental implants are widely used, few adequate studies assess masticatory function and nutrition in total edentulous patients treated with dental implants. Drawing a parallel to general healthcare and orthopaedics and the use of implants, such as hip and knee joint replacements, there are established routines for following rehabilitation and assessing the outcome after such interventions. In odontology, clinicians lack routines for such assessment after implant treatments and instructions of use are mostly focused on oral hygiene. A subjective and objective evaluation of masticatory function and nutrition should be a standard procedure for optimising masticatory function in patients with implants. The findings in the studies included in this thesis have re-evaluated the differences between implant prostheses and natural teeth. Hence, many questions raised before the work with this thesis have come closer to an answer. Other questions have arisen and are subject to new discussions.

5.1 Do dental implants and natural teeth perform equally?

No previous studies have assessed masticatory performance among people treated with bimaxillary implant-supported fixed prostheses. Studies assessing the masticatory performance of people with complete dentures, later treated with mandibular implant-supported fixed prostheses, have shown a significant improvement in masticatory performance after implant treatment (155, 156). The experimental group in Studies I and II were treated with fixed implant-supported prostheses even in the maxilla. Thus, better masticatory performance can be expected due to the bimaxillary retaining of the prostheses. However, the results exhibit a significant difference compared to people with natural dentitions. The food comminution and the mixing ability tests pointed in the same direction, i.e., inferior masticatory performance in people with bimaxillary implant-supported prostheses. Therefore, the conclusion to be drawn is that dental implants, even if considered state-of-the-art, do not perform equally to natural teeth.

5.2 Is patient-reported feedback a measure of masticatory function and success?

Studies among people with complete permanent dentition have presented no agreement between the objective and subjective evaluation of masticatory function (114). It has also been reported that the adult population, regardless of gender, experiences functional limitations due to deteriorated dental status and the use of removable dentures (157). The outcome and measure of success of prosthetic treatment are mainly based on patients' satisfaction (136). Studies have identified a weak correlation between objective, quantifiable measures, and self-reported subjective feedback, most likely representing the experienced improvement of aesthetics, comfort, and quality of life but not necessarily a successful outcome (145, 146). For instance, people treated with mandibular implant-supported prostheses according to the early loading protocol were more satisfied than those treated with the 2-stage protocol despite a higher frequency of biological and mechanical complications (158). Edentulous people treated with implants, as participants in the experimental group in Study II, are people with a history of deteriorated dental health and several episodes of treatments before coming to the stage of full mouth extraction and implant treatment. In many cases, with increased tooth mobility, poor mastication and/or long periods of non-functioning removable dentures. For these reasons, it is unsurprising that this group of people presents high satisfaction when treated with implant-supported fixed prostheses. This is reflected in the scores of OHIP-49 and JFLS-20, equivalent to those of the control group and even adult populations in Sweden (157). Important to remember is that these measures are more or less the only measures of success used in daily practice. However, Study II reflects a lack of correlation between subjective and objective measures regarding masticatory performance. Thus, subjective self-reported improvement in light of the findings in Study II, is not an appropriate measure of masticatory performance or the ultimate measure of successful treatment outcome.

5.3 Should masticatory performance be assessed when major prosthetic treatments are performed?

The clinical practice still lacks an adequate and reliable objective tool to measure masticatory performance after oral rehabilitation. Even subjective evaluations are normally not done in an established scientific procedure. Rather, it is done in a blunt manner affected by several factors. Treatment of edentulous people with bimaxillary implant-supported fixed prostheses is considered the state-of-the-art treatment of edentulism. However, chewing performance reflected in the food comminution and chewing ability tests is significantly impaired compared to people with natural teeth (Studies I and II). These differences are to some extent, even recurrent in the altered eating habits, risk of malnutrition (MNA®), risk of nutritional deficiency (SCREEN II) and increased BMI. Certainly, these findings could as well be seen in people with partial dentures or other prosthetic replacements (86). Therefore, it would be important to introduce a follow-up assessment of masticatory performance as a natural part of major prosthetic treatment. For example, by using a food comminution and/or mixing ability test. These tests claim only minutes to perform and analyse and could be done in connection with follow-up visits. Thus, objective measures are crucial for assessing masticatory function and treatment success. Not at least for securing good function and nutrition.

5.4 Is nutrition adequate among edentulous people treated with implants?

Chewing, swallowing, and nutrition depend on functioning teeth and mastication (32, 129). Infants, for instance, are fed soft food since functioning teeth are absent, and their system is not mature enough to digest solid food. On the contrary, edentulous people are expected to eat and chew all kinds of food, whether their missing teeth have been replaced with implants or not. As mentioned earlier, the masticatory performance of bimaxillary implant-supported fixed prostheses is, in various aspects, inferior to natural teeth (Study I & II). An important issue is whether dental implants perform well enough to ensure a secure swallowing process, adequate digestion, and sufficient nutrition.

The masticatory performance represented by the results of the food comminution test and the mixing ability test shows clearly that there are differences between edentulous people with dental implants and people with natural teeth (Study I & II). These measures represent only inferior performance, but there are no defined values for what is expected for normal swallowing, digestion, and absorption of nutrients. Therefore, our results, although unambiguous, do not reveal the whole picture. However, the nutritional assessment points in the direction of overweight, high-risk level nutritional deficiency, risk of malnutrition, and altered eating habits (Study III). Whether this is related to the poorer masticatory performance compared to people with natural teeth or not, requires a deeper analysis. One hypothesis is that the impact of particle size is crucial for energy and nutrient bioavailability (116, 159). The number of particles obtained after ten chewing cycles was smaller for the implant group (Study I & II). The timed number of chewing cycles to final swallowing was the same for both groups. A conclusion to be drawn is that edentulous people with implants tend to swallow larger pieces, leading to the nutritional deficiencies reflected in Study III. Another hypothesis is that malnutrition is perhaps due to the lesser variety of food (Study III). The intake of nutrients and energy could be negatively affected by the result of nutritional deficiencies. Studies illuminate the importance of, and encourage food variety to secure nutrient adequacy and prevent diseases among children (160, 161), adults (162, 163) and the elderly (164). However, nutrition is complex and subject to multifactorial influence and correlates with several findings related to health. For instance, there is a positive correlation between obesity/overweight and tooth loss (165, 166). This could indicate that edentulous participants in Study III were in the range of overweight even before being treated with implants. Thus, the nutritional deficiencies may not specifically be related to the masticatory performance of the prostheses. Instead, an explanation could be other factors related to both tooth loss and overweight/obesity. One such factor is caries, which is highly associated with the intake of sugar and with a significant correlation to high BMI and overweight (167). Sugar is also a risk determinant for other obesity and caries (168, 169). Important to conclude is that edentulous people, even if treated with bimaxillary implant-supported fixed prostheses, belong to a risk group of malnutrition.

5.5 Should the nutritional assessment be included in dental practice?

Taking the importance of nutrition for health and avoidance of disease into consideration, regular nutritional assessments are crucial. In Sweden and many other countries, visiting dental practices for regular check-ups is the rule rather than the exception. Perhaps simple and not especially time-consuming assessments, such as MNA® and Screen II, would have a great impact on revealing nutritional risks and deficiencies at early stages. Even BMI, highly correlated with morbidity and mortality (170), could as easily be measured.

Dietary records in dental practice, mainly to assess the eating frequency and sugar intake, belong to normal clinical routines. An extension and a more profound analysis of this routine could expose risks related to eating habits and a poor variety of foods.

The findings in Study III could identify even people with natural teeth with nutritional risks and deficiencies. This group may benefit from such assessments in connection with regular check-ups. These assessments are especially interesting when people with impaired masticatory function are identified. An intentional volitional increase in the number of chewing cycles would delay the swallowing process and ensure a smooth bolus transport into the oesophagus (171). Instruction and training along the way for people with impaired masticatory performance would for instance, be chewing a few more times to avoid dysphagia and better digest the food. Even reducing the food volume included in a morsel tends to increase the number of chewing cycles and thus make a bolus easier to swallow (172). Besides, food texture and volume leads to adjustments of chewing patterns to better suit the texture (173). Therefore, instructions for reducing the morsel size would be another action to take. Besides, the variety of food and intake of nutrients related to the frequency of beans, vegetables, seaweeds and nuts are associated with lower chewing efficiency among community-dwelling older individuals (174). Increasing awareness of various functional impairments, nutritional deficiencies, and risks would be a step in the right direction. When identifying nutritional risks, it is perhaps good to involve other health professionals such as dieticians and treating physicians.

In sum, nutritional and dietary assessment in dental practice could be important to increase awareness of malnutrition, alarm for nutritional risks and introduce several actions to secure a high nutritional status when needed.

5.6 Can mastication be relearned with the help of neuroplasticity of the cortex?

Various sense organs in and around the mouth ensure the connection to the cortex controlling masticatory movements and forces (34, 35). In edentulous people, even when treated with implants, teeth and sense organs inside and around the teeth are excluded from the communication process with the cortex. Hence, neuroplasticity depends on organs such as those located in the mucosa, TMJ, tongue, etc.

Cortical neuroplasticity is hypothesised to be the underlying mechanism of relearning appropriate mastication by facilitating corticomotor pathways to the relevant muscle groups. For instance, the performance of various orofacial motor tasks is believed to be improved by repeated, skilled training (175-177). In fact, repetition of a novel motor task increases performance with increased representation of the trained muscle in the motor cortex (178, 179). Studies have demonstrated dramatic changes in the organisation of the somatosensory cortex following the removal of afferent inputs or manipulation of sensory inputs in primates (180). Therefore, it is suggested that the face sensorimotor cortex can also undergo neuroplastic changes following alterations in intraoral sensory inputs (39, 181). It has previously been observed that short-term training with a complex "manipulation and split" task results in increased precision of task performance. This is enhanced by neuroplastic changes in the corticomotor pathways, related to the masseter muscle and optimisation of jaw movements in terms of reduction of the duration of various phases of jaw movements (177). Hence, these findings may be important for understanding how humans learn, re-learn, or adapt to an altered oral environment. Thus, by taking advantage of cortical neuroplasticity, it could be assumed that people with bimaxillary implant-supported prostheses and a total absence of PMRs may well be subject to cortical relearning. Perhaps, by introducing a training programme following major prosthetic treatment. This could prevent various impairments and optimise masticatory function, important to maintain adequate nutritional status.

5.7 Can the function of PMRs be re-established around dental implants?

A main difference between bimaxillary implant-supported prostheses and dentitions with natural teeth is the absence of a periodontal mechanoreceptor, playing a central role in oral sensorimotor control and encoding relevant aspects of the patterns of forces acting on the dentition (25). A natural question would be whether PMRs can be kept intact when teeth are extracted. Another is whether these can be implanted in connection to implants to maintain communication between the implants and the cortex.

Studies show that the static detection thresholds for people with natural teeth are approximately 10-fold higher than those with dental implants (182). Regarding intensive information about tooth loading on natural teeth, the threshold is 1 N for anterior teeth and 3-5 N for posterior teeth. Further, PMRs are essential in aspects of spatial and fine motor control of the mandible. However, the dynamic, i.e., vibration detection threshold, is relatively similar to natural teeth. This suggests that the transmission of vibrations is not disturbed through the osseointegrated junction (182). A thrive in the direction of re-establishing the innervation in the area around the implants should aim at establishing sensitivity to loads and aspects of spatial and fine-tuning of the motor control. Eventually, to increase tactile sensibility around dental implants, called osseoperception. A potential treatment, in theory, is using Calcitonin gene-related peptide-alpha (αCGRP). Applying the neuropeptide in the surgical site aims to promote peripheral nerve fibres regeneration and reconstruction of the neural feedback pathways around dental implants. Hence, increasing and promoting osseoperception and promoting sensorimotor functions (183). Another theory is the application of platelet-rich plasma (PRP) for the same purpose (184). Yet, there are no studies indicating that reestablishment of PMRs is possible.

5.8 Is impairment of masticatory performance correlated to biological and prosthetic complications in implant treatments?

The focus of this thesis has not been studying the issue of implant complications. However, the impaired masticatory performance is suggested to be partially related to the absence of periodontal mechanoreceptors, also connected to complications in implant treatments.

The success and survival rate of treatment with dental implants have steadily improved over the last decades (185). However, complications related to biological and prosthetic issues of implant treatment do occur, even if they are not very common. Factors that can be involved in biological complications are those related to infections, contamination, trauma from surgical procedures, excessive and /or premature occlusal loading etc. (10). Overloading has however been questioned as a cause of bone loss since bone is highly responsive to dynamic loads (186). On the other hand, overloading is highly relevant when considering prosthetic complications.

The periodontal mechanoreceptors are responsible for sensorimotor control and fine-tuning of the mandibular movements. Further, it is hypothesised that the information signalled by the periodontal mechanoreceptors is processed by the central nervous system (CNS) to regulate the levels and directions of the bite forces used during manipulative actions, e.g., during positioning of food before biting or chewing. Indeed, subjects seem to use periodontal afferent information to explicitly specify the level of force during such manoeuvres (22, 30). Furthermore, patients with dental prostheses supported by oral mucosa or osseointegrated implants show impaired force control during such tasks (42, 187). It is also hypothesised that the signals from the periodontal receptors are used in a predictive manner to adjust and adapt the motor programs employed to split and crush food during biting and chewing. The sensory information sets the parameters of the motor programme so that the intensity of the bite force is adjusted to the intrinsic properties of the food, and the bite force vector is optimised for the location of the food relative to the teeth. Thus, patients with implant-supported prostheses are expected to have impaired control of biting forces and reduced resistance to loading. For instance, biting forces generated by people wearing conventional prostheses in the posterior regions are considerably lower compared to people with full-arch implant-supported prostheses (188, 189). As a result, implant-retained constructions are supposed to be exposed to occlusal overloading to a greater extent than natural teeth. Therefore, patients treated with dental implants are expected to have a higher risk of prosthetic complications such as fractures of restorative veneers, attachment system of overdentures, the acrylic base, etc. In fact, one could claim that there is a correlation between impairments of masticatory function and complications related to implant treatment.

5.9 Why are teeth considered separated from the body? Should the treatment of edentulous people be part of the healthcare system?

During the beginning of the implant era, Brånemark met scepticism mainly in Sweden. Nevertheless, Brånemark, with his vision of helping people and curing edentulism, made a clear statement recognising that "the mouth is a much more important part of the human body than medicine and controlling agencies" (41). Several decades-old statement, but still alive and important. In most cultures worldwide, dental care seems to be separated from healthcare. In Sweden, for instance, teeth are, in terms of national dental care subsidy, only partially included in the rest of the body. The fact that speech, smiling, laughing, and social intercourse, in general, are highly associated with teeth and their function and appearance do not seem to be considered. Neither that the mouth and teeth are fundamentally connected to the gastrointestinal system and other functions of the body. Compared to orthopaedics, the healthcare field closest to prosthodontics, replacing knees, hip joints, etc., is considered a natural part of healthcare. Besides, excessive long-term training to enable the patient to use the new joint is always introduced to maintain the function. This is even though nutritional aspects are not immediately involved in the replacements. At some point, it seems like what dental care national health systems are willing to include is a political decision. This thesis and other studies have once more brought light to the importance of well-functioning mastication for the function of the rest of the body. Hence, it would perhaps be important to consider that decisions on the level of national subsidy should be based on the degree of impaired masticatory performance.

6 Limitations

According to the power analysis, the number of participants in the three studies was sufficient for the purpose. It would, however, have been convenient to increase the number for better gender distribution and a stronger understanding of masticatory dysfunction. We faced difficulties with attendance from many of the patients who had been treated with bimaxillary implant-supported prostheses. Some patients, especially those who had undergone the treatment at an old age many years earlier and were due for regular follow-up, chose not to attend. Some had moved or could not attend because of distance or health issues. Despite these facts, the studies were important, and the experimental groups are unique and representative in many aspects.

The food comminution test used in Studies I and II evaluates the number of particles after a certain number of cycles. However, quantifying 3-dimensional objects through a 2-dimensional image presents some limitations and thus is only partially reliable. Besides, small pieces and/or not completely separated were difficult to count.

On the other hand, the same standardised methodology was used for all participants in all groups. However, there was a significant correlation between the food comminution test and the validated mixing ability test as a measure of masticatory performance. Another factor motivating the use of the food comminution test is that it is relatively simple, not time-consuming and is easy to perform. Therefore, it could be applied routinely to daily clinical practice.

The dietary records, compiling and analysing the obtained data was challenging. Although clear instructions, the data collected was not consistent and always comparable. Some of the participants gave very precise amounts, ingredients, and times. Some were not as specific. The high motivation and cooperation needed for filling dietary records could explain these variations. Even the bias in the collected data related to type, amount of food, and frequency of meals have considerable impact (190). Besides, the consciousness of recording the type and amount of food consumed may alter dietary behaviour, resulting in "reactivity bias" (191). Since not all information was provided by all participants, only the type of food and times could be used as reliable measures. The amounts were not as reliable and, therefore, not considered for analysis.

Some of the data related to nutrition could probably have been explained by other factors than masticatory dysfunction related to edentulism and implant treatment. If the type of participants treated with bimaxillary implant-supported prostheses had been more common, we would have assessed various aspects before and after the treatment. Through such an approach, we would have created a better understanding of the influence of the treatment and excluded other factors that interfered with the results.

7 Conclusions

Several conclusions can be drawn from this thesis. Compared to natural dentate, people with implants show poor masticatory performance (Study I & II). However, these people do not seem to self-report any limitations in oral health-related quality of life, OHRQoL (Study II). It is also observed that people with dental implants tend to show poor nutritional status, are at higher nutritional risk, and present altered eating habits compared to natural dentate (Study III).

The studies included in this thesis show clearly that masticatory performance is impaired among people treated with bimaxillary implant-supported fixed prostheses (Study I & II). Compared to people with natural teeth, there are clear differences in performance reflected in inferior comminution and mixing ability (Study I & II). The results of the food comminution and mixing ability tests indicate a significant impairment in masticatory performance among people treated with bimaxillary implant-supported fixed prostheses compared to people with natural teeth (Study I & II). These impairments seem to have negative impact on nutrition (Study III). BMI is significantly higher, indicating overweight compared to normal weight among the dentate counterparts. The group presents even higher MNA® scores, although none of the groups is at risk of malnutrition. This result is even reflected in the SCREEN II scores, pointing in the direction of high-risk nutritional deficiency compared to a moderate risk in people with natural dentition (Study III).

Moreover, eating habits seem to be altered among people treated with bimaxillary implant-supported fixed prostheses, The variety of foods, especially fruits, seems significantly less than the dentate group (Study III). Despite these differences, subjective assessment, reflecting self- reported measures of self-reported limitations and quality of life, do not correlate with the objective measures (Study II).

8 Points of perspective

The original title of this thesis was "Optimising of masticatory function in people with dental implants". The main purpose of the studies was and still is to identify specific sensorimotor dysfunctions, functional impairments, and nutritional risks to optimise masticatory function in people with bimaxillary implant-supported prostheses and perhaps implant-supported constructions in general. Some questions have been clarified, some have not, and new ones have arisen.

Previous studies have shown that about one-third of patients with dental implants presented severe problems in dividing hard food samples into pieces (42). With this knowledge and findings in Studies I & II in mind, a future study would focus on further analysis of three-dimensional jaw movements. The kinematics of these movements can be measured using a custom-built 3D- jaw tracker, and jaw position with an accuracy of 0.1 mm can be detected. Deviations in Studies I & II participants with poor masticatory performance can thus be identified and further analysed. For example, a reduced ability to generate temporal, spatial and intensive information in the cortex can be detected.

Another potential study is screening of muscle activity with the help of the multi-channel surface EMG technique. The results from this screening could be used to distinguish variations in jaw muscle activity. Through analysis, differences between participants and disabilities to adjust force levels and directions to intrinsic properties could be revealed.

As mentioned above, the cortex can learn, relearn, and adapt to the altered oral environment through neuroplasticity. This ability could be used by introducing a training programme for re-learning a standardised, repetitive chewing sequence to participants with poor masticatory performance. Such improvements could be evaluated through various masticatory performance measurements, three-dimensional jaw movements and muscle activity before and after introducing training. Edentulous patients treated with bimaxillary implant-supported fixed prostheses are especially interesting for this investigation.

An extension of the suggested assessment of neuroplasticity would consider whether nutritional status and risk change over time after interchanging a training programme. Future studies could even perform a more profound biochemical assessment of nutrition and add another dimension to the relationship between masticatory function and nutrition in people with altered sensorimotor control.

During the work with this thesis, one question was whether artificial intelligence could be used to identify individuals at risk for masticatory impairments and swallowing dysfunctions. Through analysing facial movements obtained from the video recordings from Studies I and II, following the processing of algorithms, they could be used to identify the vital landmarks during chewing and swallowing. Therefore, one could identify impairments through a simplified methodology with the help of a mobile phone camera.

9 Acknowledgements

There is a time for everything and a season for every activity under heaven. … a time to plant, a time to uproot…, a time to tear down and a time to build, a time to weep and a time to laugh…, a time to scatter stones and a time to gather them…, a time to be silent and a time to speak… - Ecclesiastes 3:1-8.

The time for writing this thesis was perhaps not the most appropriate. Performing the work behind, establishing and running a clinic, and treating patients with the highest ambition of quality and care, did not seem possible. A tragic pandemic changing the world, and many people's lives forever, stood in the way. But, against all odds, this thesis has become a reality. In the best country in the world, nothing is impossible. Thank you for being a safe haven and opening your doors to success…

A life is a past, a presence, and a future.
A journey.
Along the road, many people have enriched my life,
and contributed to the person I am.
My deepest gratitude and love to you all.

Anastasios Grigoriadis for your understanding, engagement, and positivism. Never hesitating or doubting and always being available and helpful. Many times, during the work, we used the word unique. I would like to dedicate the word to you. You have been a solid supervisor. Most important of all is that you have become a friend for life.

Abhishek Kumar for your warm heart. Your broad knowledge and analytic ability. Never being satisfied unless perfection is achieved is worth great admiration. You have been such a representative of security and thoroughness. I'm looking forward to new projects under our wings.

Mats Trulsson for your positive attitude and always being welcoming and believing in me. For having made this work possible through years of research in the field. You have, for decades, paved the way for many of us. This thesis is not an end. It is the next chapter, a new start for the work you once started.

Nabeel Almotairy for your generosity and for never hesitating to help. For being open-handed and supportive in such a thorough way, regardless of distance and location. Your contribution has been very important, and I hope our paths cross in the future.

Anna Karlsson for being such an excellent and supportive colleague. For your great work and effort with the project. More future work is needed, and I hope to pass the baton to you!

Elena Wester for your great contribution and generosity with all important data during the first study.

Joannis Grigoriadis for your positive and encouraging attitude. For your support and generosity during the work.

Praktikertjänst for giving me the opportunity to conduct this research. For all the generous support at all levels. **Ann-Chriztine Ericsson** and **Ann-Britt Östlund** for believing in me and my ability to run my doctoral studies besides all other work.

GHP Specialisttandläkarna Nacka, my friends, and former colleagues. For allowing me to use your database and clinic while collecting the data for this project. For all the knowledge and experience you provided me through probably the most important years of my career.

My beloved staff at Tandvården Sergel for our journey. For your support, patience and understanding. For always being there for me. For carrying our values. This thesis wouldn't have been written without you by my side through these years. You are a great joy and happiness.

Marie Strömbom for your endless loyalty and belief in me. For our 21 years! For walking the road with me despite all difficulties. You are such a unique person. The world would need more of you. My trust and gratitude are as limitless as your loyalty.

Torhild and Roger for giving me safety and security, always standing by me, and being proud. In a harsh world, many people would have needed people like you.

Thomas Kallus my mentor and friend. For your presence, faith in me and never-ending support through all years. For always being available and generous. For our first meeting 22 years ago, a first step into a future of success. I wish every person a mentor and friend like you.

My sisters and families for always being by my side and for your endless faith in me. For being my greatest fans. For always expressing pride and happiness for my success. For always being a helping hand whenever needed.

My parents for the adamant foundation you gave me. For your eternal love and embracement. For raising me to the person I am. For never hesitating or doubting my ability to reach my goals. For all the lessons in life. For always being helpful, supportive, and understanding.

Johanna for your unconditional love and precious presence in my life. For your help at all levels during this journey. For listening to me with genuine curiosity and engagement. For your big heart, warmth, understanding and support. For our never-ending talks. For being “one of the kind”.

Fadi for being the best brother one can be. For being a friend, a supporter, and a professional counterpart. For always and selflessly being a shoulder to lean on. For always taking care of everyone else before yourself. I owe you an entire life. I owe you all I am. This book is for us!

My daughter Claudia for your understanding, your matureness, your excellence, your success. For always being natural, upright, and honest. For always being the best daughter, I could wish you to be. You are and have always been my inspiration. This book is for you!

My son Liam for your positive and enthusiazing attitude. For giving me hope. For your smile. For being you no matter what. For your belief in me and always making me the proudest father on earth. For convincing me that everything is possible. This book is for you!

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11 Appendices

11.1 JFLS-20 Jaw Functional Limitation Scale

För varje nedanstående fråga, ange graden av begränsning i käkarna under den senaste månaden. Om det har varit omöjligt att utföra aktiviteten, ringa in "10"

		Ingen begränsning										Stor begränsning
1.	Tugga seg mat	0	1	2	3	4	5	6	7	8	9	10
2.	Tugga bröd (tex hårt bröd)	0	1	2	3	4	5	6	7	8	9	10
3.	Tugga kyckling (tex tillagad i ugnen)	0	1	2	3	4	5	6	7	8	9	10
4.	Tugga kex	0	1	2	3	4	5	6	7	8	9	10
5.	Tugga mjuk mat (tex makaroner, kokta grönsaker, fisk)	0	1	2	3	4	5	6	7	8	9	10
6.	Äta mjuk mat som inte behöver tuggas (tex potatismos, äppelkräm, pudding, puréer)	0	1	2	3	4	5	6	7	8	9	10
7.	Gapa tillräckligt stort för att ta en tugga av ett äpple	0	1	2	3	4	5	6	7	8	9	10
8.	Gapa tillräckligt stort för att ta en tugga av en smörgås	0	1	2	3	4	5	6	7	8	9	10
9.	Gapa tillräckligt stort för att tala	0	1	2	3	4	5	6	7	8	9	10
10.	Gapa tillräckligt stort för att dricka ur en mugg	0	1	2	3	4	5	6	7	8	9	10
11.	Svälja	0	1	2	3	4	5	6	7	8	9	10
12.	Gäspa	0	1	2	3	4	5	6	7	8	9	10
13.	Tala	0	1	2	3	4	5	6	7	8	9	10
14.	Sjunga	0	1	2	3	4	5	6	7	8	9	10
15.	Se glad ut	0	1	2	3	4	5	6	7	8	9	10
16.	Se arg ut	0	1	2	3	4	5	6	7	8	9	10
17.	Fnysa	0	1	2	3	4	5	6	7	8	9	10
18.	Kyssas	0	1	2	3	4	5	6	7	8	9	10
19.	Le	0	1	2	3	4	5	6	7	8	9	10
20.	Skratta	0	1	2	3	4	5	6	7	8	9	10

11.2 OHIP-49 Oral Health Impact Profile

Hur ofta under den senaste månaden har Du upplevt följande situationer, pga problem med Dina tänder, mun, proteser eller käkar? Markera för varje påstående det alternativ som bäst motsvarar Din upplevelse. Använd "Gäller ej mig" om Du anser att påståendet ej passar för Dig.

		Gäller ej mig	Mycket ofta	Gansk a ofta	Ibland	Sällan	Aldrig
1.	Svårigheter med att tugga någon form av mat	0	1	2	3	4	5
2.	Svårigheter med att uttala ord	0	1	2	3	4	5
3.	Lagt märke till att en tand ser ut som den ska	0	1	2	3	4	5
4.	Känt att ditt utseende har påverkats	0	1	2	3	4	5
5.	Känt att du haft dålig andedräkt	0	1	2	3	4	5
6.	Känt att smakförmågan har försämrats	0	1	2	3	4	5
7.	Har haft mat som fastnat i tänderna eller proteserna	0	1	2	3	4	5
8.	Känt att din matsmältning försämrats	0	1	2	3	4	5
9.	Känt att dina proteser inte passat ordentligt	0	1	2	3	4	5
10.	Har haft smärta i Din mun	0	1	2	3	4	5
11.	Varit öm i käken	0	1	2	3	4	5
12.	Har haft huvudvärk	0	1	2	3	4	5
13.	Har haft känsliga tänder vid intag av varm eller kall mat eller dryck	0	1	2	3	4	5
14.	Har haft tandvärk	0	1	2	3	4	5
15.	Har haft smärtor i tandköttet	0	1	2	3	4	5
16.	Har haft obehag med att äta mat	0	1	2	3	4	5
17.	Har haft ömma ställen i munnen	0	1	2	3	4	5
18.	Har haft obekväma proteser	0	1	2	3	4	5
19.	Har varit oroad pga tandproblem	0	1	2	3	4	5
20.	Känt mig osäker	0	1	2	3	4	5
21.	Känt Dig eländig	0	1	2	3	4	5
22.	Känt Dig besvärad med Ditt utseende	0	1	2	3	4	5
23.	Känt Dig spänd	0	1	2	3	4	5
24.	Funnit att Ditt tal varit otydligt	0	1	2	3	4	5
25.	Personer har missuppfattat en del av de ord Du sagt	0	1	2	3	4	5
26.	Känt att det varit mindre smak i maten	0	1	2	3	4	5
27.	Inte kunnat borsta tänderna ordentligt	0	1	2	3	4	5
28.	Har varit tvungen undvika att äta viss mat	0	1	2	3	4	5
29.	Har haft otillfredsställande kost	0	1	2	3	4	5
30.	Har inte kunnat äta med Dina proteser	0	1	2	3	4	5
31.	Undvikit att le	0	1	2	3	4	5
32.	Har varit tvungen att avbryta måltider	0	1	2	3	4	5
33.	Din sömn har blivit störd	0	1	2	3	4	5
34.	Varit upprörd	0	1	2	3	4	5
35.	Haft svårt att koppla av	0	1	2	3	4	5
36.	Känt Dig deprimerad	0	1	2	3	4	5
37.	Din koncentration har påverkats	0	1	2	3	4	5
38.	Blivit generad	0	1	2	3	4	5
39.	Undvikit att gå ut	0	1	2	3	4	5
40.	Varit mindre tolerant mot Din make/maka eller familj	0	1	2	3	4	5
41.	Haft besvär att komma överens med andra människor	0	1	2	3	4	5
42.	Varit något irriterad på andra människor	0	1	2	3	4	5
43.	Haft svårigheter att utföra de vardagliga sysslorna	0	1	2	3	4	5
44.	Känt att Din allmänhälsa försämrats	0	1	2	3	4	5
45.	Lidit någon ekonomisk förlust	0	1	2	3	4	5
46.	Har varit oförmögen med att uppskatta andra människors sällskap	0	1	2	3	4	5
47.	Känt att livet varit mindre tillfredsställande	0	1	2	3	4	5
48.	Varit totalt oförmögen fungera	0	1	2	3	4	5
49.	Har Du varit oförmögen att arbeta fullt ut	0	1	2	3	4	5

11.3 MNA®
Mini Nutritional Assessment

Mini Nutritional Assessment
MNA®

Nestlé NutritionInstitute

Efternamn:			Förnamn:	
Kön:	Ålder:	Vikt, kg:	Längd,cm:	Datum:

Fyll i poängsiffran i rutorna för bedömning (screening) och summera. Om poängen är 11 eller mindre fortsätt med del II för att få en gradering av näringstillståndet.

Screening, del I

A Har födointaget minskat under de senaste tre månaderna på grund av försämrad aptit, matsmältningsproblem, tugg- eller sväljproblem?
0 = ja, minskat avsevärt
1 = ja, minskat något
2 = nej, ingen förändring ☐

B Viktförlust under de senaste tre månaderna
0 = ja, mer än 3kg
1 = vet ej
2 = ja, mellan 1 och 3kg
3 = nej, ingen viktförlust ☐

C Rörlighet
0 = är säng- eller rullstolsbunden
1 = kan ta sig ur säng/rullstol men går inte ut
2 = går ut med eller utan hjälpmedel ☐

D Har varit psykiskt stressad eller haft akut sjukdom under de senaste tre månaderna?
0 = ja 2 = nej ☐

E Neuropsykologiska problem
0 = svår demens eller depression
1 = lindrig demens
2 = inga neuropsykologiska problem ☐

F Body Mass Index (BMI) = vikt i kg / (höjd i m)²
0 = BMI mindre än 19
1 = BMI 19 till mindre än 21
2 = BMI 21 till mindre än 23
3 = BMI 23 eller mer ☐

Screeningresultat (Subtotal max 14 poäng) ☐☐

12-14 poäng:	Normal nutritionsstatus
8-11 poäng:	Risk för undernäring
0-7 poäng:	Näringsbrist

För en grundligare bedömning, fortsätt med frågorna G-R

Screening, del II

G Har eget boende? (ej särskilda boendeformer / sjukhus)
1 = ja 0 = nej ☐

H Intar mer än 3 ordinerade läkemedel dagligen?
0 = ja 1 = nej ☐

I Har trycksår eller annat hudsår?
0 = ja 1 = nej ☐

Ref. Vellas B, Villars H, Abellan G, et al. *Overview of the MNA® - Its History and Challenges.* J Nut Health Aging 2006 ; 10 : 456-465.
Rubenstein LZ, Harker JO, Salva A, Guigoz Y, Vellas B. *Screening for Undernutrition in Geriatric Practice : Developing the Short-Form Mini Nutritional Assessment (MNA-SF).* J. Geront 2001 ; 56A : M366-377.
Guigoz Y. *The Mini-Nutritional Assessment (MNA®) Review of the Literature - What does it tell us?* J Nutr Health Aging 2006 ; 10 : 466-487.

Mer information finns på : www.mna-elderly.com

J Äter fullständiga huvudmål per dag?
0 = 1 fullständigt huvudmål
1 = 2 fullständiga huvudmål
2 = 3 fullständiga huvudmål ☐

K Äter eller dricker vanligtvis
- minst en mejeriprodukt dagligen (mjölk / ost / yoghurt)? ja ☐ nej ☐
- minst två portioner baljväxter eller ägg per vecka ja ☐ nej ☐
- fisk, fågel eller kött varje dag? ja ☐ nej ☐

0.0 = inget eller ett ja svar
0.5 = två ja svar
1.0 = tre ja svar ☐.☐

L Äter minst två frukter eller två portioner med grönsaker dagligen?
0 = nej 1 = ja ☐

M Dricker dagligen (vatten / juice / kaffe / te / mjölk / öl)?
0.0 = mindre än 3 glas / mugger
0.5 = 3 till 5 glas / mugger
1.0 = mer än 5 glas / muggar ☐.☐

N Kan äta själv eller behöver hjälp vid måltiden?
0 = behöver mycket hjälp vid måltiden
1 = äter själv men med svårighet
2 = äter själv utan problem ☐

O Bedömer själv sitt näringstillstånd som
0 = svårt undernärd / felnärd
1 = är osäker om sitt näringstillstånd / vet ej
2 = har inga näringsproblem ☐

P I jämförelse med andra i samma ålder uppfattar sitt hälsotillstånd som?
0.0 = inte så bra som andras
0.5 = vet ej
1.0 = lika bra som andras
2.0 = bättre än andras ☐.☐

Q Överarmens omkrets i cm (Mid Arm Circumference, MAC)
0.0 = MAC mindre än 21 cm
0.5 = MAC 21-22 cm
1.0 = MAC mer än 22 cm ☐.☐

R Vadens omkrets i cm (Calf Circumference, CC)
0 = CC mindre än 31 cm
1 = CC 31cm eller mer ☐

Screening, del II (max. 16 poäng) ☐☐.☐
Screening, del I ☐☐.☐
Total bedömning, del I + del II (max. 30 poäng) ☐☐.☐

MNA resultat

24-30 poäng	☐	normal nutritionsstatus
17-23.5 poäng	☐	risk för undernäring
Mindre än 17 poäng	☐	undernärd

11.4 SCREEN II
Seniors in the Community: Risk Evaluation of Eating and Nutrition

SCREENII poäng

Vad har du för matvanor?

Namn:	Datum:

- Välj ett alternativ som stämmer bäst in på dig. För varje fråga ska du bara kryssa för **ett alternativ**
- Dina svar ska spegla dina **typiska matvanor**
- Lämna gärna egna **kommentarer** bredvid frågorna

1. Hur skulle beskriva din aptit/matlust?
   - $_4$☐Mycket god
   - $_3$☐God
   - $_2$☐Mindre god
   - $_0$☐Dålig

2. Brukar du hoppa över måltider?
   - $_4$☐Aldrig eller sällan
   - $_2$☐Ibland (någon gång varje vecka)
   - $_1$☐ Ofta (flera gånger varje vecka)
   - $_0$☐Nästan varje dag

3. Drar du ner på eller undviker viss mat, för att du inte ska må dåligt?
   - $_4$☐Jag äter nästan all sorts mat.
   - $_2$☐Jag drar ner på viss mat och det går bra.
   - $_0$☐Jag drar ner på viss mat men jag tycker det är svårt.

   - $_2$☐Ibland (någon gång varje vecka)
   - $_1$☐ Ofta (flera gånger varje vecka)
   - $_0$☐Nästan varje dag

4.
   a. Har din vikt förändrats under de senaste 6 månaderna?
   - $_4$☐Nej, min vikt har inte förändrats mer än något kilo
   - $_0$☐Jag vet inte hur mycket jag väger eller om min vikt har förändrats

   Ja, jag har gått upp…

   - $_0$☐mer än 5 kilo *Kommentar?*
   - $_1$☐ 3 till 5 kilo
   - $_2$☐Ungefär 2 kilo

   Ja, jag har gått ner

   - $_0$☐ mer än 5 kilo *Kommentar?*
   - $_1$☐ 3 till 5 kilo
   - $_2$☐ Ungefär 2 kilo

b. Har du försökt att förändra din vikt under de senaste 6 månaderna?

$_4$☐ Ja
$_4$☐ Nej
$_0$☐ Nej, *men den förändrades ändå*

c. Tycker du om att du väger…?

$_4$☐ mer än du borde
$_4$☐ lagom mycket
$_0$☐ mindre än du borde

5. Hur många gånger äter du frukt och grönsaker per dag?
T.ex. konserverade, färska, frysta eller som juice.

$_4$☐ Fem eller fler
$_3$☐ Fyra
$_2$☐ Tre
$_1$☐ Två
$_0$☐ Färre än två

6. Hur ofta äter du kött, köttpålägg, ägg, fisk, fågel, ELLER alternativ till dessa?
T.ex. ärtor, bönor, linser, nötter, tofu (sojabönsprodukt), quorn (bas på svampprotein och äggvita)

$_4$☐ Två gånger *per dag* eller oftare
$_3$☐ En till två gånger *per dag*
$_1$☐ En gång *per dag*
$_0$☐ Mer sällan än en gång *per dag*

7. Hur ofta äter du eller dricker mjölkprodukter?
T.ex. mjölk, mjölk i matlagning, glass, yoghurt, ost, alternativ till mjölk som berikande sojadrycker

$_4$☐ Tre gånger *per dag* eller oftare
$_3$☐ Två eller tre gånger *per dag*
$_2$☐ En eller två gånger *per dag*
$_1$☐ Vanligen en gång *per dag*
$_0$☐ Mer sällan än en gång *per dag*

8. Hur ofta dricker du per dag? *T.ex. vatten, te, örtdryck, juice, läskedryck, cider, lättöl men ej övrig alkohol (stor mugg=250 ml, glas=175 ml, kaffekopp liten=125ml)*

$_4$☐ 11 glas eller mer	(2000 ml eller mer)
$_3$☐ 7 till 10 glas	(1250 – 1750 ml)
$_2$☐ 4 till 6 glas	(750 – 1000 ml)
$_1$☐ Ungefär 3 glas	(ungefär 500 ml)
$_0$☐ Mindre än 3 glas	(mindre än 500 ml)

9. Brukar du hosta, sätta i halsen eller känna smärta när du sväljer mat ELLER dryck?

$_4$☐ Aldrig
$_3$☐ Sällan
$_1$☐ Ibland
$_0$☐ Ofta eller alltid

10. Har du svårt att bita eller tugga mat?

$_4$☐ Aldrig
$_3$☐ Sällan
$_1$☐ Ibland
$_0$☐ Ofta eller alltid

11. Brukar du använda näringstillägg eller ersättning för vanlig mat?
T.ex. energidrycker, näringsdryck, pudding, berikningsprodukter,

$_4$☐ Aldrig eller sällan
$_1$☐ Ibland
$_0$☐ Ofta eller alltid

12. Äter du en eller flera måltider om dagen tillsammans med någon?

0☐ Aldrig eller sällan
2☐ Ibland
3☐ Ofta
4☐ Nästan alltid

13. Har du problem med att införskaffa (köpa och/eller få hem) dina matvaror? *Problemet kan vara dålig hälsa, handikapp, begränsad inkomst, avsaknad av transposrt, väderförhållanden eller att hitta någon som kan handla åt dig.*

4☐ Aldrig eller sällan
2☐ Ibland
1☐ Ofta
0☐ Nästan alltid

14.

a. Vem brukar laga din mat?

☐ Jag själv
☐ Jag delar matlagnigen med någon annan
☐ Ofta lagar någon annan min mat
☐ Oftast värmer jag färdiglagad djupfryst mat

b. Vilket påstående angående matlagning passar bäst in på dig?

Jag lagar alltid/oftast min mat *själv* och…

4☐ …jag tycker om att tillaga de flesta av mina måltider.
2☐ …*ibland* tycker jag att matlagning är jobbigt.
0☐ …*Oftast* tycker jag att matlagning är jobbigt.

Någon annan lagar alltid/oftast min mat och…

4☐ …jag *är nöjd* med kvalitén på den mat som andra lagar åt mig
0☐ …jag *är inte nöjd* med kvalitén på den mat som andra lagar åt mig

Eventuell kommentar angående matlagningen:

Tack för din medverkan