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Karolinska Institutet, Stockholm, Sweden

OBJECTIVE AND SUBJECTIVE MASTICATORY FUNCTION IN OLDER INDIVIDUALS

Per Elgestad Stjernfeldt



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Objective and subjective masticatory function in older individuals

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By

Per Elgestad Stjernfeldt

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Principal Supervisor:

Associate professor Inger Wårdh
Karolinska Institutet, Sweden
Department of Dental Medicine
Unit Oral Diagnostics and Surgery

Opponent:

Professor Martin Schimmel
University of Bern, Switzerland
Department of Reconstructive Dentistry

Examination Board:

Professor Åke Tegelberg
Malmö University, Sweden
Faculty of Odontology

Co-supervisor(s):

Associate professor Anne-Marie Boström
Karolinska Institutet, Sweden
Department of Neurobiology, Care Sciences and Society

Professor Helle Wiik
Göteborg University, Sweden
The Sahlgrenska Academy
Institute of Health and Care Science

Associate professor Gerd Faxén Irving
Karolinska Institutet, Sweden
Department of Neurobiology, Care Sciences and Society

Associate professor Aron Naimi-Akbar
Malmö University, Sweden
Faculty of Odontology, Division 4

To

Pekka Elgestad

Margaretha Stjernfeldt

Clara and Andrea.

“Researchers are more inclined to use each other’s toothbrush than each other’s measurement instrument”

Susan Picavet – Thesis 2001

”Det finns mitt i skogen en oväntad glänta som bara kan hittas av den som gått vilse.”

Tomas Tranströmer

POPULAR SCIENCE SUMMARY OF THE THESIS

The ability to eat and masticate food is an important part of dental health and well-being, both from a quality of life perspective and as part of social life. For older individuals, community-dwelling and institutionalized, it is a vital part not only from a psychological perspective but also for general health. The scientific community has put a lot of effort to explore how oral health and the ability to eat food affects eating habits and nutritional status. Research has also been done to see if there is a link between masticatory function and risk of cognitive decline.

Dental professionals play an important part to uphold and restore dental health, but what clinicians assess to be good oral masticatory function does not necessarily correspond to what the patients perceive. The aim of this thesis was to explore how older individuals assess their own ability to eat food and what they consider to be important in this process, but also how clinicians can assess and measure this function. The thesis also explored if it is possible to detect associations between mastication, nutritional status and cognitive decline in older individuals, some of them dependent on support in their daily life.

The thesis consists of four published studies. **Study I** was a systematic review where I reviewed published scientific literature to identify methods that had been developed to measure the ability to masticate. The identified methods were also graded and assessed if they could be used in a clinical setting.

In Study II, I wanted to know what older individuals thought about their ability to masticate and if there were some important aspects to consider for future research. Older individuals were invited to speak freely about the topic in an interview study.

Study III was based on data from the Swedish Adoption/Twin Study of Aging. I wanted to see if the number of occluding teeth could be linked with cognitive decline in a 22-year follow up. **Study IV** is based on data from older individuals with care-dependency. I wanted to explore whether the number of functional tooth units corresponded to how these individuals perceived their masticatory ability? I also looked at how objective and subjective masticatory function were possibly associated with nutritional status?

In Study I, the systematic review, 46 different methods were identified. Only a few were applicable in a clinical environment and few were rated as *strong* for their measurement abilities. The interviews in **Study II**, taught me that older individuals tend to overrate their ability to masticate food by a process of adaptation to adjust to a decreased oral function. Further, replacement of missing teeth, does not necessarily result in improved eating and nutritional habits. **Study III** and **IV** showed no link between masticatory function and onset of dementia, or any of the nutritional variables. There were also weak connections between subjective and objective masticatory function. However, there is need for further research in this area to find valid methods to measure both subjective and objective masticatory ability, that can be used in both clinical and research contexts.

ABSTRACT

Introduction: Oral health in the older population has improved, both in Sweden and in a global perspective. Oral health that has been associated to other, more general health perspectives such as nutrition and cognition, but also presents new challenges for the dental community. Oral health is a broad construct, but it has been shown that when older patients rate different oral health related concepts, the ability to masticate food is important.

Objective: The overall aim of this thesis was to explore how to assess objective and subjective masticatory function in older individuals, their possible relationships and association to nutrition as well as cognitive functions.

Methods and results: Study I systematically investigated and identified methods that have been developed to objectively assess masticatory function, also known as masticatory performance and to rate their measurement properties. Bibliographic databases were searched, including MEDLINE, Embase, Web of Science Core Collection, Cochrane, and Cinahl. Eligible papers that satisfied predefined inclusion and exclusion criteria were appraised independently by two investigators. Four other investigators independently appraised any measurement properties of the methods according to the consensus-based standards for the selection of health measurement instruments checklist. The qualities of the measurement properties were evaluated using predefined criteria. The level of evidence was rated by using data synthesis for each MP assessment method, where the rating was a product of methodological quality and measurement properties quality. Forty-six out of 9,908 articles were appraised, and the assessment methods were categorized as comminution ($n = 21$), mixing ability ($n = 23$), or other methods ($n = 2$). Different measurement properties were identified, in decreasing order construct validity ($n = 30$), reliability ($n = 22$), measurement error ($n = 9$), criterion validity ($n = 6$), and responsiveness ($n = 4$).

Study II focused on older individual's subjective and self-perceived notion of their masticatory function, known as masticatory ability. The aim of the study was to explore what factors seem to be important for older individuals' masticatory ability and how it impacts daily life. Qualitative methodology and in-depth interviews were used, and the design was inspired by the qualitative method Grounded Theory. The final sample consisted of twelve older participants. Three categories developed from the data; Deteriorating oral health and functional loss, Eating habits, Prosthetic rehabilitation and function. A core category named Adaptation emerged that describes how individuals successfully adapt to a decreased function and despite this develop a positive view of their masticatory ability.

Study III was a retrospective longitudinal study that examined the association between reduced posterior occlusal support and cognition in different cognitive domains and whether poor masticatory function increased the risk of dementia. Data came from a population-based study with up to 22 years of follow-up of 544 cognitively intact adults aged ≥ 50 . Cognitive domains were assessed at baseline and at follow-ups and masticatory function was assessed using the Eichner Index and categorized according to the number of posterior occlusal zones. At baseline, 147 (27.0%) participants were placed in Eichner category A, 169 (31.1%) in B and 228 (41.9%) in C. After the age of 65, participants in Eichner category B and C showed an accelerated decline in spatial/fluid abilities. Eichner categories B or C were not associated with an increased risk of dementia, compared to category A.

In study IV a group of 355 individuals with care dependency and functional limitations, aged 60 and older were included. By home visits, the participants underwent an oral examination and answered chewing related questions. Nutritional status was assessed using the Mini Nutritional Assessment. A total of 196 individuals met the age requirement. Of these, 86 subjects were able to answer the questions. The study did not report any concluding significant associations between the subdomains of masticatory function or the nutritional variables.

Conclusion: Methods to assess masticatory performance are often labor intensive and not fitted to a clinical setting. Further research is needed to find masticatory measurement methods, that are useful both in clinical contexts and research. Older individuals with at deteriorating oral function tend to overrate their masticatory ability and self-reported questionnaires seem less useful. With the chosen instruments in this thesis, a low number of occluding contacts was not associated to an increased risk of dementia or nutritional variables.

LIST OF SCIENTIFIC PAPERS

- I. Elgestad Stjernfeldt, P, Sjögren, P, Wårdh, I, Boström, A-M. Systematic review of measurement properties of methods for objectively assessing masticatory performance. Clin Exp Dent Res. 2019; 5: 76– 104.
- II. Stjernfeldt, P, Faxén-Irving, G, Wårdh, I. Masticatory ability in older individuals: A qualitative interview study. Gerodontology. 2021; 38: 199–208.
- III. Dintica CS, Marseglia A, Wårdh I, Stjernfeldt Elgestad P, Rizzuto D, Shang Y, Xu W, Pedersen NL. The relation of poor mastication with cognition and dementia risk: a population-based longitudinal study. Aging (Albany NY). 2020 Apr 30;12(9):8536-8548.
- IV. Stjernfeldt PE, Faxén Irving G, Wårdh I, Lundqvist R, Lantto A. The Relation between Masticatory Function and Nutrition in Older Individuals, Dependent on Supportive Care for Daily Living. Int J Environ Res Public Health. 2022 May 10;19(10):5801.

Scientific papers not included in the thesis

1. Elgestad Stjernfeldt P, Wårdh I, Trulsson M, Faxén Irving G, Boström AM. Methods for objectively assessing clinical masticatory performance: protocol for a systematic review. Syst Rev. 2017 Jan 26;6(1):20..

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LIST OF ABBREVIATIONS

APOE	Apolipoprotein
BMI	Body Mass Index
CC	Calf Circumference
COSMIN	Consensus-based Standards for the selection of Measurement Instruments
GOHAI	General Oral Health Assessment Index
GT	Grounded Theory
HR	Hazard Ratio
IPT	In Person Testing
LMM	Linear Mixed-effects Model
MA	Masticatory Ability
MAC	Mid Arm Circumference
MBF	Maximum Bite Force
MF	Masticatory Function
MNA	Mini Nutritional Assessment
MP	Masticatory Performance
OHaBF	Oral Health and Bite Function
OHRQoL	Oral Health Related Quality of Life
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROM	Patient-Reported Outcome Measurement
RCT	Randomized Clinical Trial
SATSA	The Swedish Adoption/Twin Study of Aging
SES	Social Economic Status

1 INTRODUCTION

The oral health of the older population in Sweden has vastly improved in the last fifty years. Older individuals are able to retain their dentition, at least partly, through their whole life span. This can be considered a successful feat by the professionals working in the field of dentistry; however, this also presents new challenges for the dental community.

The concept *oral health* can be described in a purely biological context, presumably as the absence of oral disease, but the definition has evolved to a more multi-dimensional construct which also includes psychological and social frameworks. The World Health Organization has broadened the definition to include the concept of social well-being (1). In an attempt to incorporate a social-environmental concept oral health has been described by Dolan et al: *as a comfortable and functional dentition which allows individuals to continue in their desired social role* (2).

Oral Health-Related Quality of Life (OHRQoL) as a construct can be defined as the impact of oral health on an individuals' ability to function and their perceived well-being in psychosocial domains. The premise is that OHRQoL affects an individuals' general well-being and therefore has important implications for both researchers and dental practitioners concerned with geriatric dentistry.

OHRQoL has been defined as a construct which can be divided into different sub-domains, for instance *Social, Pain/Discomfort, Psychologic* and *Functions* (3). Oral functions can then be further divided into two different concepts, *Speech* and *Mastication*. It has been shown that when older patients rate different oral health related concepts, the ability to masticate food is important, if not the most important factor when it comes to OHRQoL (4). Surely the ability to masticate food would be an important concept not only in the domain of oral function but also in a social and psychological context.

This thesis has tried to explore the phenomenon called *masticatory function*, how it is measured in a clinical context, how it is perceived subjectively in older individuals and how it is linked to other general health aspects.

1.1 MASTICATION

Mastication is the first step in the digestive process and is integrated with the swallowing process as it involves the mixture of solid foods in preparation for swallowing. The masticatory system is capable to exert huge forces with a force equivalent to lifting a persons

own weight(5). However, the masticatory system is also capable to execute fine precise or subtle movements. This spectrum of force control allow humans to prepare different types of solid foods despite the bite size or texture (5).

Like speech, mastication is a *voluntary* movement, but it also needs to be fined tuned by *reflexes*, swallowing being an example of a very complex reflex response requiring coordination of multiple muscles as the food bolus is transported from the oral cavity to the pharynx. The motor-control during mastication is also synchronized through *cyclic* movements involving the trigeminal system that is hard wired in the brain through a rhythmical neuro signaling originating from the brainstem (5, 6). These rhythmic chewing cycles are independent and can continue without the need of sensory feedback, but these movements need to be finetuned to avoid injury of the oral tissue and to allow efficient fragmentation of solid food.

This complex process involves the control of the orofacial muscles, including the masticatory muscles, which is fine-tuned by the cortex in combination with sensory feedback from *muscle spindles* and *periodontal mechanoreceptors*. Muscle spindles are mechanoreceptors located in the belly of most masticatory muscles, being more prevalent in the jaw-closing muscles, and they play an important part in the stretch reflexes during mastication

During mastication the brain sends signals along the α -motor neurons innervating the masticatory muscles to make them contract, while also sending signals via γ -motor neurons innervating the muscle spindles and activating them. The muscle spindles in turn send back afferent signals along large and myelinated Ia-sensory nerves. These Ia afferents travel along the same nerve trunk as the efferent motor-neurons which is a different arrangement compared to the spinal nerves where the cell bodies of Ia afferents are located in the dorsal root ganglia. The afferent signals then pass to the trigeminal motor nucleus where they form synapses with the trigeminal motor nerves that innervate the masticatory muscles. This arrangement allows muscle spindle induced stretch reflexes to form very fast, in about 7-8ms. This stretch reflex pathway allows the masticatory muscles to respond and compensate for changes in resistance during mastication of solid food (5).

Similarly, mechanoreceptors located in the periodontium and the bony socket play an important part in the reflex control of mastication. These receptors are sensitive to force applied directionally. Mechanoreceptors also give rise to the subjective sensation about the pressure on the teeth while also providing proprioceptive information important to the motor control during mastication (7).

This complex neuro-muscular process allows the dentition to process the food for further transportation down the esophagus without self-injury. Saliva also plays an important part in mastication as the salivary mucin binds the food particles into a slippery food bolus to facilitate the swallowing process. It also dissolves taste-substances and lubricates the oral tissues. *The masticatory-salivary reflex* is triggered by sensory input from proprioceptors in the oral cavity, including mechanoreceptors in the periodontal ligament and muscle spindles. Chewing therefore increases salivary secretion(5).

1.2 MASTICATORY FUNCTION

Masticatory function (MF) is defined as the ability to masticate solid food, however there is no established terminology in the scientific community.

MF can be divided in two sub-categories. The first category is the objective and quantifiable capacity of an individual to comminute or mix a solid food (8). There are two approaches to evaluate this objective capacity, either by evaluating to what extent a food bolus is processed after a number of chewing strokes or by observing how well a food bolus is processed enough to trigger swallowing, also known as the *swallowing threshold* (9). In this thesis the objective definition will be defined as “*masticatory performance*” (MP). Since the work with this thesis started efforts have been made to reach a more established consensus of these different definitions which are not necessarily aligned to those used in this thesis. It has been proposed that MP is only assessed with the number of chewing cycles and not through swallowing threshold (9). This thesis includes both these characterizations under the definition of MP.

The other category, known as “*masticatory ability*”, is defined as the perceived or subjectively assessed masticatory function of an individual. It can be assessed either by using visual analogue scales or through questionnaires (10-12), some of which have been validated (11, 12) to assess self-perceived masticatory quality, discomfort or food intake.

While it could be presumed that both definitions, MP and MA, reflect the same underlying construct, there seems to be no or very weak correlation between the two (13, 14).

1.3 MASTICATORY PERFORMANCE

Masticatory performance (MP) is defined as the ability of an individual to masticate solid food. As such it is an objective phenomenon that can be quantifiable in an experimental setting. The two determinants that have been identified as the main predictors of MP are number of occluding tooth contacts and maximum bite force (MBF) (15-18).

Loss of occluding tooth contacts has been shown to reduce MP in experimental studies. Full denture wearers have to use significantly more chewing strokes but still swallow bigger size food particles compared to dentate aged adults (15, 19). Implant supported lower dentures seem to improve MBF and give the wearer an ability to chew tougher food (20).

1.4 MASTICATORY ABILITY

Masticatory ability (MA) can be described as an individual's subjective or self-assessed assessment of how well they are able to masticate solid food.

1.5 MASTICATORY FUNCTION AND HOW ITS MEASURED

Diagnostic measurements are often based on morphological deviations in tissue like tooth decay, pathophysiological findings or physiological processes, while others, like headache, can only be diagnosed by their symptoms. Measurements that have been developed to assess MP use outcome measurements in different kinds of performance tests.

In 1902 Gaudenz described that MP is related to the particle size of a test food after a defined chewing sequence (21). Since then many different methods to assess MP have been developed for research settings. Generally, these methods can be divided into *comminute* and *mixing test*.

Comminute tests measures how well an individual fragment a certain test food, often within a defined number of chewing cycles. Other types of tests include the use of gummy jelly that release glucose when chewed or encapsulated fuchsin beads that release fuchsin dye which then can then be analyzed by a spectrophotometer. Two-colored chewing gum or wax can also be used in comminute tests. When the test food is chewed the two colors become mixed and indicate how well the test food has been masticated.

A number of methods or tests have been developed to measure MP but there is no measurement that has been widely adopted as a “golden standard” in the clinical context.

Health-related measurements and information can also be derived from other sources such as verbal reports. Patient-Reported Outcome Measurement (PROM) have also been used to assess masticatory ability.

Questionnaires measuring OHRQoL, like Geriatric Oral Health Assessment Index (GOHAI) (22) often include items concerning mastication, related discomfort and food-intake. Specific

questionnaires or screening tests measuring MA have also been developed (10-12, 23) but there are disparities concerning assessment of their measurement properties (24).

1.6 MASTICATORY FUNCTION AND HEALTH

In the last twenty years a growing number of scientific publications suggests that oral health and mastication can influence cognitive and general health during aging. It has been suggested that reduced masticatory function and oral health can have: indirect effect on systematic health through nutritional intake and indirect or direct effect on cognitive health(25).

1.6.1 Masticatory function and nutritional status

Poor oral health and reduced MF has been shown to relate to nutritional intake (26), but it has been reported that decreased MA has a greater impact on an older individual's quality of life than nutritional status (26, 27). Self-reported OHRQoL has been associated with risk of malnutrition or malnutrition (28) in institutionalized elderly. A study conducted on a more generalized population showed that MP was correlated with OHRQoL but not to body composition (29).

Several studies have assessed how MF relates to different nutritional variables (30-32). A significant relationship has been shown between MP and Body Mass Index (BMI), where obese patients had a lower MP compared to overweight and normal weight subjects (31). Other studies show no association between nutritional status and MP (33, 34).

Improved masticatory function after oral rehabilitation does not necessarily lead to improved dietary intake (20, 35, 36).

1.6.2 Masticatory function and cognitive function

At the end of the 1990s several animal studies were produced in Japan indicating that reduced mastication had impact on different cognitive dimensions (37-40).

A changed food texture to a more easily chewable and reduced masticatory activity has been shown to lead to cognitive degradation in mice. Mice fed with a soft diet showed loss of spatial memory (41), hippocampal degeneration (42, 43), reduced synaptic formation in the brain (43) and reduced learning capacity. Rodents fed hard- or soft-diet also showed significant different expression of genes of microglia cells in the brain (44).

A soft diet reduces the sensory input to the brain from afferents in the teeth, oral cavity and masticatory muscles, which leads to neurological degeneration (42). Loss of teeth and masticatory function could also lead to a stress-induced process with elevated levels of corticosterone which negatively affects the hippocampal memory process (45). Reduced masticatory function could also lead to a disruption of the cholinergic neurotransmitter system which has been associated with spatial memory function in rodents (46-48)

1.6.1.2 Oral health and cognitive function

The *Nun study* concluded that the participants with the fewest teeth had the highest risk of prevalence and incidence of dementia. Since then a number of publications have been published that indicate a relationship between cognitive function and oral health/MF (49).

1.6.1.3 Masticatory ability and cognitive function

A Swedish population study showed that individuals who had a possible onset of dementia also had an impaired ability to chew hard types of food (50). MA, not tooth loss, seemed to relate to the cognitive decline but other studies have not shown such associations (33). MA has also been related to cognitive performance in different neurological tests (51). A growing body of literature has suggests a possible relationship between self-reported MA and cognitive function (52-54) but a causal relationship is yet to be proven.

1.6.1.4 Masticatory performance and cognitive function

Several studies have also examined a possible relationship between objective MP tests and cognitive function (55). Positive relationships has been shown between MP and cognitive function in individuals diagnosed with dementia (34, 56) but most studies do not assess MP but number of teeth (49).

1.6.1.5 Causal relationship and methodological challenges

Intervention studies are needed to prove a possible causal relationship. This presents many ethical and methodological difficulties, but such studies are planned (57).

Previously published literature uses different methodological concepts to assess MF. While some use self-reported MA other use methods to objectively assess MP. Since there seems to be a weak relationship between MA and MP it can be questioned if they measure the same underlying construct. Geriatric patients with cognitive impairment tend to overestimate self-

evaluated MA (58). It would be of great benefit to reach a scientific consensus on which method would be most advantageous to use in future research.

2 RESEARCH AIMS

The general aim of this thesis was to explore how to assess objective and subjective masticatory function in older persons, their possible relationships and relation to nutrition as well as cognitive functions.

The specific aims were

- | | |
|-----------|--|
| Study I | To identify methods for objectively assessing masticatory performance.
Evaluate measurement properties of the identified methods. Compare measurement properties of the identified methods. Identify adverse events during development or validation of methods that were studied. |
| Study II | To explore older individuals' experienced masticatory ability and the impact of masticatory ability in daily life. |
| Study III | To examine the association between poor masticatory ability (reduced posterior occlusal support) and cognitive trajectories in different domains and investigate whether poor masticatory ability may increase the risk of dementia, using longitudinal data from a population-based study with up to 22 years of follow-up. |
| Study IV | To assess the relationship between masticatory performance and masticatory ability and to assess the relationship between masticatory performance and masticatory ability and nutritional variables in older, care-dependent individuals. |

3 MATERIALS AND METHODS

3.1 STUDY DESIGN

In this thesis both quantitative and qualitative methods were used in separate studies for the general aim, see Table 1.

Study I was a systematic review aimed to identify different methods developed to assess masticatory performance but also to evaluate and compare their measurement properties with the expectation to find a method that could be used in a clinical setting in future studies.

Study II focused on masticatory ability. A qualitative approach was used to explore the phenomenon of MA and generate possible hypotheses of what seems to be important when it comes to self-reported masticatory function.

Study III investigated the effect of poor MP on cognitive trajectories and dementia risk in older adults. 544 cognitively intact adults aged ≥ 50 was followed for up to 22 years. The cognitive domains verbal, spatial/fluid, memory, and perceptual speed were assessed at baseline and follow-ups. Dementia was ascertained according to standard criteria. MP was assessed using the Eichner Index and categorized according to the number of posterior occlusal zones: A (all four), B (3-1), and C (none).

Study IV investigated a possible relationship between MP and MA and to assess the relationship between MP and MA and nutritional variables. From a group of 355 individuals with care dependency and functional limitations, individuals aged 60 and older were selected. Data was obtained by oral examination and questionnaires. Nutritional status was assessed using the Mini Nutritional Assessment (MNA).

3.1.1 Systematic reviews of measurement properties

Systematic reviews aim to identify, evaluate and synthesize the findings of all relevant individual studies, thereby making the available evidence more accessible (59). One of the aims of this thesis was to identify different methods that had been developed in the scientific community to assess MP and rate their individual measurement properties.

A measurement property is a characteristic reflecting a distinct aspect of the measure's quality (60). An international panel with the aim to identify key measurement properties, develop a measurement taxonomy, define the terms of taxonomy and develop formal standards for evaluating instruments (61, 62) formed Consensus-based standards for the

selection of health measurement instruments (COSMIN). Since then COSMIN has developed different tools to conduct a systematic review of outcome measurement instruments and to provide an overview of important quality aspects of instruments (61). In Study I the COSMIN checklist was used to evaluate the measurement properties of different methods that had been developed to measure MP.

3.1.2 Qualitative individual interview studies

For this thesis a qualitative method inspired by Grounded Theory (GT) was used with an open-ended exploratory approach using inductive reasoning(63).

A qualitative approach does not necessitate a pre-existing theory. Instead, the purpose of Study II was to generate a theory about masticatory ability in relation to masticatory function and important key variables. GT is a method that is used to create a hypothesis-generating theory. The data collection begins with an open question in an interview setting. During analysis of the transcribed material, which is performed concurrently with data collection, repeated ideas or concepts become apparent. As new data are added, these concepts, often called codes, are constantly compared and reanalyzed. The codes can then be grouped into categories and subcategories that could form the basis for a new emerging theory, often based on a core category(63). However, the results cannot be generalized.

3.1.3 Retrospective longitudinal studies

In Study III a retrospective longitudinal observational methodology was used to examine if MP could be used as a predictor of cognitive function. Longitudinal studies repeatedly observe certain variables of a population during a defined period and can be used to identify predictors of certain conditions or diseases. Retrospective studies use existing data to follow the progression of a population back in time, but they cannot establish causality.

3.1.4 Cross-sectional observational studies

Study IV was a cross-sectional observational study. In a cross-sectional study data is analyzed from a population at a specific point in time. They can be used to describe some features of the population, however no conclusion about causality can be drawn.

Table 1.

Thesis	Study I	Study II	Study III	Study IV
Design	Systematic review	Qualitative interview study	Retrospective longitudinal study	Cross-sectional observational
Population	Not applicable	Adults ≥ 65 years old	Cognitively intact adults aged ≥ 50 at baseline	Older persons with codependency and functional limitations
Number	n=46	n=12	n=544 at baseline	n=196 with clinical data n=86 with questionnaires
Data sources	Five databases	Individual interviews	SATSA	Clinical data and questionnaires
Time of collection	2017	2016-2017	1989-2012	2019-2020
Outcome	Identify methods Evaluate and compare measurement properties Identify adverse events	Categories in an explanation model	Eicher index, cognitive trajectories in different domains	Eichner index, MNA, BMI, Calf- and upper arm circumference, questions related to masticatory ability

Overview of the studies included in this thesis.

3.2 STUDY I

3.2.1 Information sources and literature search strategy

The overall search strategy was developed with the assistance and consultation of librarians at Karolinska Institute University Library who ran the systematic literature searches. For further information of the search strategy see Appendix 1.

Five databases were searched from inception until to January 2017: MEDLINE, Embase, Web of Science Core Collection, Cochrane, and Cinahl. In addition, Google Scholar identified more potentially relevant articles. The literature search was updated in December 2017 to identify any relevant articles published since the initial search in January 2017.

See Figure 1 for flowchart of identified and included articles.

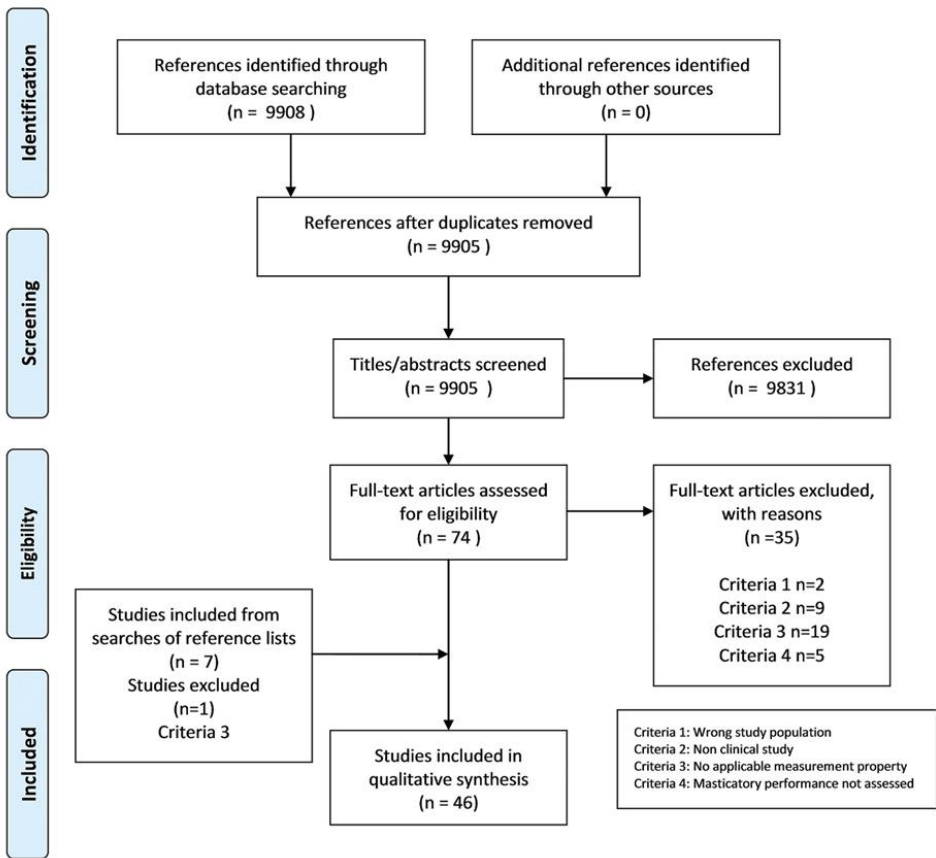


Figure 1. PRISMA flow chart

3.2.2 Inclusion criteria

Full-length articles published in English and in a scientific journal.

Contain measurement properties of methods used to assess masticatory performance in adults (ages \geq 18).

3.2.3 Exclusion criteria

Published studies that used interview methods and self-reported questionnaires; qualitative studies; case studies; expert opinions, editorial articles; animal studies; human studies (persons with severe oral health complications); and unavailable, full-text studies.

3.2.4 Instruments

The quality of the methodology of the included studies and the measurement properties was evaluated COSMIN. COSMIN contains 12 boxes that are used to assess methodological quality of studies evaluating measurement properties and defines four domains: validity, reliability, responsiveness, and interpretability with related measurement properties and their characteristics (61), see Figure 2. For each of the measurement property, the COSMIN consists of five to 18 items that cover methodological standards and each item is rated on a four-point scale (i.e., poor, fair, good, and excellent). By applying the lowest rating for each item in one box, an overall score is separately generated for each measurement property. A study is rated as poor, fair, good, or excellent regarding methodological quality for each of the assessed measurement properties.

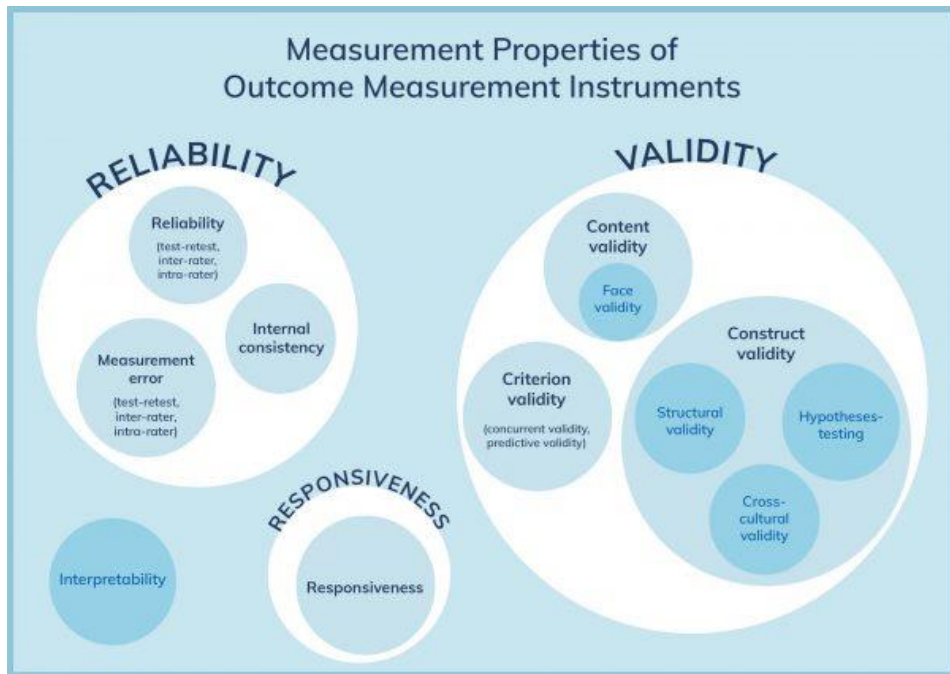


Figure 2. Measurement properties according to COSMIN

3.2.4.1 Definitions

COSMIN defines the domain validity as “the degree to which an instrument truly measures the construct(s) it purports to measure. The types of validity evaluated in Study I were:

Criterion validity which indicates degrees to which a measurement instrument's scores adequately reflect another method or instrument that is considered gold standard. Criterion validity can only be assessed when a gold standard is available.

Construct validity is defined as “the degree to which the scores of an instrument are consistent with hypotheses.” Validation requires the formulation of specific hypotheses to acquire evidence that the instrument is measuring what it claims to measure.

The other three domains defined by COSMIN, that was used in Study I were Responsiveness, Reliability and Measurement error.

Responsiveness is defined as “the ability of an instrument to detect change over time in the construct to be measured”.

Reliability is defined as “the degree to which the measurement is free from measurement error”.

Measurement error is defined as “the systematic and random error of a patient's score that is not attributed to true changes in the construct to be measured”.

3.2.4.2 *Quality of measurement properties*

The qualities of measurement properties were established according to criteria developed by Terwee and colleagues(64). According to these criteria, measurement properties are rated as positive, negative, or indeterminate. These criteria are presented in Table 2. In Study I, one reviewer rated all measurement properties, while the review team confirmed the rating by consensus.

Table 2.

Validity Property	Rating	Quality criteria
Construct validity – hypothesis testing	+	Correlation ≥ 0.50 with an instrument measuring the same construct, or $\geq 75\%$ of the results in accordance with the hypotheses and correlation with related constructs is higher than with unrelated constructs
	?	Solely correlations determined with unrelated constructs
	+	Correlation < 0.50 with an instrument measuring the same construct, or $< 75\%$ of the results in accordance with the hypotheses, or correlation with related constructs is lower than with unrelated construct
Criterion validity	+	Convincing arguments that gold standard is “gold” and correlation with gold standard ≥ 0.70
	?	No convincing arguments that gold standard is “gold” or doubtful design or method
	-	Correlation with gold standard < 0.70 , despite adequate design and method

Responsiveness	
Rating	Quality criteria
+	Correlation with an instrument measuring the same construct ≥ 0.50 , or at least 75% of the results are in accordance with the hypotheses or area under the receiver operating characteristics (ROC) curve, and correlation with related constructs is higher than with unrelated constructs.
?	Solely correlations determined with unrelated constructs
-	Correlation with an instrument measuring the same construct < 0.50 or $< 75\%$ of the results are in accordance with the hypotheses or area under the ROC curve, or correlation with related constructs is lower than with unrelated constructs

Reliability		
Property	Rating	Quality criteria
Measurement error	+	Minimal important change $>$ smallest detectable change, or minimal important change outside the limits of agreement
	?	Minimal important change not defined
	-	Minimal important change \leq smallest detectable change, or minimal important change equals or inside limits of agreement
Reliability	+	Intraclass correlation/weighted kappa ≥ 0.70 or Pearson's $r \geq 0.80$
	?	Neither Intraclass correlation/weighted kappa or Pearson's r determined
	-	Intraclass correlation/weighted kappa < 0.70 or Pearson's $r < 0.80$

3.2.4.3 Evidence level

Data synthesis for each method occurred by combining the methodological quality of included studies and measurement properties, a method developed by Dobson et al.(65). First, all studies were quality assessed separately, and then for each method. Studies that evaluated the same method were given an individual score, and the results were then pooled in an overall evidence synthesis. The level of evidence was synthesized across the studies with an overall conclusion, namely, *unknown, conflicting, limited, moderate, or strong* level of evidence, see Table 3.

Table 3.

Evidence levels	
Level	Criteria
Strong	Consistent findings, multiple studies of good methodological quality OR ≥ 1 study of excellent methodological quality
Moderate	Consistent findings, multiple studies of fair methodological quality OR ≥ 1 study of good methodological quality
Limited	One study of fair methodological quality
Conflicting	Conflicting findings
Unknown	Only studies of poor methodological qualities

Evidence level criteria

3.3 STUDY II

3.3.1 Information sources - Qualitative interviews

All individual interviews were conducted by a dentist with many years of clinical experience but not one of the authors. A senior researcher in the team with experience of qualitative

research, provided instruction and training in qualitative methods. Deeper insights and skills were gained by the interviewer from the literature.

3.3.2 Inclusion/exclusion criteria and recruitment process

The participants were recruited from the public dental clinic at the Academic center for geriatric dentistry (ACT) in the central part of Stockholm, Sweden. This clinic is focused on treating older patients, both with and without daily living support. Participants were selected purposively using “snowball recruitment,” in which the data and results from each interview encourage further recruitment. Recruitment was ongoing and conducted concurrently with data analysis until saturation or no new relevant information was achieved.

Pfeiffer's test was used in the first six interviews to assess whether the participants could answer the interview questions adequately. In the following data collection procedure, this test was not used, as the interviewer was able to conclude that the participants were cognitively fit to answer and discuss the issue of masticatory ability adequately. The final sample consisted of twelve elderly participants, the first nine between 82 and 90 years old and the following three between 67 and 73 years old. Seven were men and five were women. The interviewer had not met any of the participants before-hand, nor did the interviewer have any information about them except gender and age.

First, nine individuals were interviewed. Initially, a minimum age of 75 years was set as an inclusion criterion. The age limit was then lowered to 65 years to possibly detect the experiences of more functional aspects. The data analysis showed that the oldest participants (around 85-90 years) had become more adapted to functional changes in their MA.

3.3.3 Instruments

3.3.3.1 Pfeiffer's test

Pfeiffer's test also known as Short Portable Mental Status Questionnaire (SPMSQ), consists of 10 items concerning orientation, information, memory and calculation, and is used as a dementia screening tool, but not as a diagnostic tool (66).

3.3.3.2 Interview guide

The guide included a number of topic areas of masticatory ability, food and dental health. The participants were asked open questions and the subsequent discussions meandered in different directions depending on what came to the person's mind when reflecting on their masticatory ability. The participants were asked to speak freely about the topic while the

interview guide was looked upon more as a list of relevant questions for the interview aim but with the order of the questions spontaneously influenced by the participants.

3.3.4 Data analysis

The interviews were tape recorded and the analysis process started as soon as the first interview was verbatim transcribed. All authors read the text in total, then meaningful units or codes were sorted out to form a manifest or descriptive analysis. The codes were constantly compared and sorted into categories and subcategories. New participants were recruited based on the gaps identified during this process. After the data collection was saturated, or no new relevant information became apparent, a “core category” or theory model emerged. This was the latent part of the analysis.

3.4 STUDY III

3.4.1 Information sources – Swedish Adoption/Twin Study of Aging

For Study III data from The Swedish Adoption/Twin Study of Aging (SATSA) was used. SATSA began in 1984 when a comprehensive questionnaire (Q1), including items concerning family, adult, and working environment, health status, health related behaviors, was sent to all individuals registered in the Swedish Twin Registry who were separated at an early age and reared apart. Twins reared together was used as a control sample (67).

2845 individuals received the Q1 and 71 % responded (n=2 018). Further questionnaires were then sent in a three- year interval up until 1993. Data was also attained through in person testing (IPT) which included extensive health assessments, including a cognitive battery, physical and functional health examinations. The first IPT was carried out in 1986-1988 and included those twins who both had responded to Q1 and were 50 years or older (n=861). A total of 859 individuals have participated in at least one IPT and 76% have participated in three IPTs or more.

Dental status was first collected during IPT2 through IPT9, therefore, only the participants who were assessed at IPT2 were included in Study III (n=595) and was based on data from, spanning 22 years. 544 participants remained after excluding for missing information on dental status, prevalent dementia or cognitive impairment.

3.4.2 Instruments

3.4.2.1 SATSA health assessment

The health assessment used in Study III included 12 tests assessing four cognitive domains: verbal abilities, spatial/fluid, memory and perceptual speed. Dementia was diagnosed at follow-up examinations according to criteria from the DSM–III or DSM–IV. Consensus meeting were held to determine clinical diagnosis of dementia in which performance on cognitive tests, health, daily functioning, and medical records were reviewed.

During in-person testing (IPT), examination was conducted by nurses. They recorded the number of teeth and type of fillings if present. Information was also attained with a questionnaire whether the participants used prostheses (partial-denture or whole denture). They were also asked if they had problems with gingivitis (no/yes or sometimes) or periodontal disease (yes/no).

3.4.2.2 Eichner index

The Eichner index was used in Study III as an assessment as variable for MP (68). The index is based on the number of occluding contact pairs in the premolar and molar regions. These regions are divided into four supporting zones, two in the premolar, and two in the molar regions. By noting the presence or absence of intermaxillary tooth contact in these four zones, a patient is classified as belonging to one of three groups, which are further divided into ten sub-groups. In the present study, we divided the participants into the following three main groups: A, have occlusal contacts in all four posterior support zones; B, have occlusal contacts in one to three zones of contact or within the anterior area only; and C, have no occlusal contacts at all, see Figure 3.

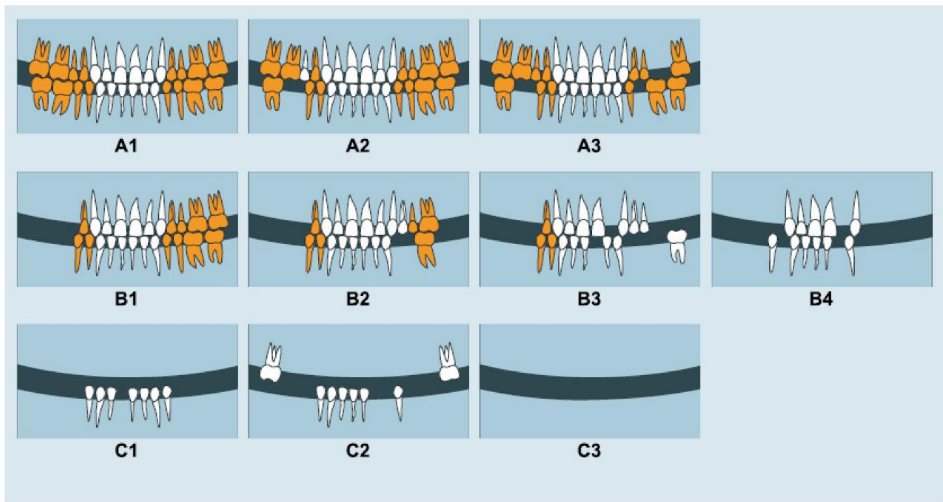


Figure 3. Eichner index

3.4.3 Statistical methods

3.4.3.1 *Linear mixed-effects model*

The linear mixed-effects model (LMM) is similar to linear regression, with the added benefit of being able to handle longitudinal and clustered or hierarchical data, i.e. when there is non-independence in the data. In this thesis, the LMM was used in Study III to test the effect of Eichner index category on cognitive decline in different domains over 22 years.

3.4.3.2 *Cox proportional-hazards model*

Cox regression is a method to investigate association between survival time of study participants and one or more predictor variables. In Study III, Cox regression was used to estimate the association between Eichner categories and the risk of dementia diagnosis during a time span of 22 years. Cox regression estimates hazard ratios (HRs) across an underlying time scale, under the assumption that hazards are proportional for all levels of the predictor over time. The HRs are ratios of event rates between different exposure groups.

3.5 STUDY IV

3.5.1 Information sources - The register of increased financial support for dental care

In Study IV, the register of increased financial support for dental care was used for sampling of the study groups. Individuals who are entitled to the financial support system are recorded in the register at the county council. About 7000 individuals are recorded in the register in Norrbotten County.

3.5.2 Inclusion criteria

Participants 60 years or older were included.

3.5.3 Exclusion criteria

Individuals who were tube fed or did not masticate or process food per os were excluded.

3.5.4 Characteristics of the study population

Study IV was part of a cross-sectional survey, based on oral examinations and questionnaires among a group of 355 individuals with care dependency and functional limitations who were randomly selected from the register of increased financial support in Norrbotten County, Sweden, in 2015.

The majority lived in nursing homes or in group housing, with a range of 20-97 years. They underwent an oral examination and answered chewing related questions. The same examiner conducted all examinations. Their cognitive ability to complete these questions was measured using the SPMSQ. For participants with visual or motor impairments, the questions were completed by the study's research assistant or care personnel/family members. After adjusting for the age requirement (≥ 60 years of age) $n=196$ individuals remained.

3.5.5 Instruments

3.5.5.1 Eichner index

The Eichner index, which was previously described, was used in Study IV as an assessment as variable for MP. In the present study, we divided the participants into the following three main groups: A had occlusal contacts in all four posterior support zones; B had occlusal contacts in one to three zones of contact or within the anterior area only; and C had no occlusal contacts at all.

3.5.5.2 GOHAI

The General Oral Health Assessment (GOHAI) was developed in the USA and measures OHRQoL in three domains: *physical function*, *psychosocial function* and *pain and discomfort* (22). The questionnaire uses a Likert scale where responses are scored in one of five categories: *always*, *often*, *sometimes*, *seldom*, *never*. For study IV specific items concerning mastication were selected as variables to represent MA. These were:

How often did you limit the kinds or amounts of food you eat because of problems with your teeth or dentures?

How often did you have trouble biting or chewing any kinds of food, such as firm meat or apples?

How often were you able to swallow comfortably?

How often were you able to eat anything without feeling discomfort?

In the analysis, we dichotomized the answers to always/often and never/seldom.

3.5.5.3 Oral Health and Bite Function

In Study IV certain items from the questionnaire Oral Health and Bite Function (OHaBF), together with the items from GOHAI, was used as variables for MA. OHaBF is a Swedish questionnaire developed in Norrbotten County to assess an older individuals self-perceived assessment of oral health and function. The following items were used in Study IV:

I need help with my oral health.

The participant can answer *yes* or *no*. If the answer is *yes*, one or more of the following statements can be chosen:

Help with pain from the jaws

Help to improve my chewing function

Help to improve my speaking function

Help to improve my appearance

In Study IV the participant would score if they had answered *yes* to the statement: *Help to improve my chewing function*.

A further two items from OHaBF were also used in Study IV:

Are you able to chew adequately?

How would you rate your ability to eat food?

Responses are scored on a Likert scale of 1–5, from *very good* to *very poor*.

3.5.5.4 *Mini Nutritional Assessment*

MNA was used to assess nutritional variables. MNA is a commonly used tool, designed and validated for nutritional screening and assessment to help identify elderly patients who are malnourished or at risk of malnutrition (69). The original version was used. This contains 18 items with a max score of 30, where 24–30 points indicate normal *nutritional status*, 17–23.5 at *risk of malnutrition* and <17 *malnutrition*.

Today the short version (SF) is more common. The MNA-SF contains the first part of the original MNA and is validated towards this.

Specific items from the questionnaire were also selected and analyzed independently:

Body mass index (BMI kg/m²), which was dichotomized into *BMI < 19–21* and *BMI > 21*.

Calf circumference (CC), which was scored as being either less or more than 31 cm.

Mid-arm circumference (MAC), which was scored as being either less than 21 cm, between 21–22 cm or more than 22 cm.

Certain items concerning eating habits were also used:

How many main meals do you eat per day?

Do you eat two or more servings of fruit or vegetables per day?

Can you eat without assistance?

3.5.6 **Statistical methods**

3.5.6.1 *Chi-square test*

The Chi-square test can be used to test whether different categorical variables are independent or related (70). For Study IV the Chi-square test was used to determine if there were associations between the Eichner index categories and the items from the questionnaires. Chi-square test was also used to test associations between Eichner index categories and the different nutritional variables.

3.6 ETHICAL CONSIDERATIONS

Study I did not require an ethical approval as it is a systematic review that uses publicly accessible documents. Study II, III and IV were all ethically approved by the Regional Ethical Review Board, following the principals of the Declaration of Helsinki(71). Study II was approved by the Regional Ethical Review Board in Stockholm (protocol 2016/5:2, reference no. 2016/6-31/5). Participants received oral and written information about the study and were guaranteed confidentiality. Written consent was obtained from all the participants. The participants could decline further participation at any stage of the study, without negative consequences.

For Study III and SATSA, SATSA received ethical permissions from the Ethics Committee at Karolinska Institutet and the Regional Ethical Review Board in Stockholm, 84:61; 98-319; 2010/657-31/3. Participants also signed a repository consent that allowed their data to be shared. Written or oral informed consent was collected from all participants in SATSA prior to their inclusion in the study. Similarly, in SATSA, all participants received a letter that described the purpose, content, and duration of the study. They were assured confidentiality and anonymity as part of the informed consent process.

Study IV was approved by the Regional Ethical Board in Umeå 2013-46-31M and this ethical approval was supplemented to fulfil Study IV aims and was approved (2019-03620). Since the study population of Study IV consisted of individuals with functional limitations and dependency some of them had difficulties to express themselves and could therefore be considered vulnerable. The information about the study was sent by letter. An advocate could assist the participant if needed and they were offered a home visit if they had difficulties to be able to visit the dental clinic.

In Study II, III, and IV the participants were informed that their involvement in the study was voluntary and that they were free to drop out at any point in time. For data collected, ethical requirements clearly state that the consent must be voluntary. This means that information of participants who dropped out was not available from registries or interviews. Privacy was further insured assigning one administrator to access the registries for study III and IV and interviews for Study II. In all datasets, researchers obtained anonymized data without any reference to a person's name or personal identification number; data were tagged with only a study-specific identification number.

4 RESULTS

4.1 STUDY I

4.1.1 Included articles in Study I

Methods for assessing masticatory performance were categorized into three main categories; *comminution* (n=21), *mixing ability* (n=23) and *other* (n=2), see Appendix 2. Different domains and measurement properties were reported of which the most common was the validity of the method for assessing masticatory performance (n=36, 78%). The majority of the studies (n = 32, 70%) were rated as poor or fair. Only studies with methodological quality rated as fair, good, or excellent are reported in this thesis.

4.1.2 Comminution methods

These methods were defined into four categories:

Sieve or optical scanning methods that assess fragmentation and particle-size distribution with either single or multiple sieves or through some type of optical scanning and digital image analysis.

Gummy jelly (GJ) methods that involve measuring glucose extraction released from chewed GJ; amount of released glucose is associated with the degree to which test food is fragmented and hence to masticatory performance.

Fuchsin beads methods that use encapsulated fuchsin beads as test food to assess masticatory performance; fuchsin dye is released into the capsule when the beads are chewed, and the concentration of released dye, which is proportional to masticatory performance, is quantified with a spectrophotometer.

Colorimetric methods that assess test food fragmentation through release or binding of dye from a solution; dye concentration is assessed with a spectrophotometer, which is proportional to masticatory performance.

4.1.3 Mixing ability tests

For assessing masticatory performance, mixing ability methods involve two-color gum or wax (as test food) and color-changeable gum. The included studies described assessment of various digital analysis software apps and subjective color or bolus scales.

4.1.4 Other methods

One study reported construct validity of the Eichner index, which measures the number of posterior occlusal contacts in relation to masticatory performance.

4.2 METHODOLOGICAL QUALITY AND LEVEL OF EVIDENCE

The quality of each reported measurement property and evidence level are described below. Only studies that were graded *fair*, *good*, or *excellent* for their methodological quality are included in the summary.

4.2.1 Two-color chewing gum

Construct validity was reported in three studies regarding two-color chewing gum, one was rated as *excellent* quality, while two were rated *fair*. One study rated *fair* reported conflicting research findings based on the age of the study participants, with negative findings for young participants and positive findings for the older participants.

Four studies have attempted to evaluate the reliability of visual color or bolus scales. One was rated *good*-quality and two were *rated fair*. Measurement error was reported in three studies all of *fair* quality.

Construct validity of methods using two-colored chewing gum was rated *Strong level of evidence* using at digital software analysis. *Moderate level of evidence* for construct validity was also reported for a similar method. One study also reported *moderate* level of evidence for reliability, while all other studies reported *limited/unknown* level of evidence.

4.2.2 Two-color wax

Four studies reported construct validity of methods using two-colored wax, three were rated *good*-quality and one was rated *fair*. One *fair*-quality study reported responsiveness. One *poor* and one *fair* quality reported reliability. Finally, one study rated *good* reported on measurement error.

Moderate level of evidence for construct validity was reported by four studies using two-color wax which is analyzed by a mixing ability index or digital image software.

4.2.3 Color changing gum

Construct validity was evaluated in four studies rated as *fair* quality. Two *fair* rated studies also evaluated reliability. *Limited/unknown* level of evidence was reported for criterion validity and construct validity.

4.2.4 Sieve and optical scanning methods

One *fair* quality study reported construct validity using an optical scanning method. Two *good* and two *fair* quality studies reported reliability using the sieve method. Measurement error was also assessed in a study rated *fair*.

Limited or unknown level of evidence was reported from all the included studies that were categorized into sieve and optical scanning methods concerning construct or criterion validity. One study reported strong *level of evidence* of the measurement property reliability.

4.2.5 Gummy Jelly

Two studies evaluated construct validity and were rated *fair* and *good* respectively. Both studies evaluated masticatory performance by means of a glucose meter or visual scale. Reliability was reported in a *good* quality study.

Limited/unknown level of evidence was reported from all studies categorized in the gummy jelly group.

4.2.6 Fuchsin beads

One *good*-quality study evaluated the measurement property of reliability.

4.2.7 Other methods

Construct validity of the Eichner index as an assessment of MP, was reported in one study of *fair* quality with *limited/unknown level of evidence*.

4.2.8 Summary

The studies reporting methods using two-color chewing gums and digital analysis revealed moderate to strong level of evidence for construct validity and moderate level of evidence for reliability using a visual scale. Moderate level of evidence was also reported for construct validity using two-colored wax.

Strong level of evidence was reported for reliability using Optosil Comfort as a test food with multiple sieve method. Finally, moderate level of evidence was reported for reliability using gummy jelly as a test food and using a visual scale for assessment.

4.3 STUDY II

Twelve informants participated in Study II and are briefly described in Table 5.

Table 5.

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Age	83	89	86	88	87	90	89	73	67	72	69	72
Gender	F	M	F	F	M	M	M	M	M	F	M	M
Removable prosthodontics	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No

Characteristics of informants Study II

Three categories and a core category emerged from the data; see Table 6 .

Table 6.

Core category	Adaptation		
Categories	Deteriorating oral health and function	Eating habits	Prosthetic rehabilitation and function
Sub-categories	Loss of teeth	Avoidance of certain food types	Improved masticatory ability after treatment
	Weakened dentition	Food preparation	Retained dietary habits after treatment
	Declined oral sensorimotor regulation	Adjusted social behaviour	

An overview of the categories in Study II

The category *Deteriorating oral health and function* describes the informant's perception of their dental health and function in general. A process of a gradually deteriorating oral health and function was described and how it had changed throughout life. Loss of teeth was a topic often brought up by the informants. Some informants described a sensation that their mouth felt "different" in old age when processing the food bolus.

The second category *Eating habits* describes how the informants adjusted their dietary habits such as chewing patterns or choice of food, as well as social behaviours, such as avoiding eating in public. The informants felt that their restored teeth were too weakened to be able to withstand the mechanical forces of chewing. They avoided certain types of hard or tough food and prepared food in different ways, for example by boiling or grating.

The third category *Prosthetic rehabilitation and function* describes how the masticatory ability of the informants had been affected by prosthetic rehabilitation. Participants who had received fixed prosthodontics were generally positive. Those with removable dentures experienced more difficulties. Informants also described that prosthetic rehabilitation had improved their masticatory ability, but this had not led to a change in dietary habits.

The core category that emerged was *Adaptation*. It became apparent that the participants had described an ongoing process of adaptation, that would determine how the participants perceived their masticatory ability. An informant who had successfully adapted to reduced function would develop a positive view of their masticatory ability, and vice versa.

The informants described a process of adaptation to a compromised oral function through an active adjustment of habits. Some had not really considered that they had altered their lifestyle to adapt to a deteriorated oral function and did not seem to perceive problems. An adaptive process had taken place which was possible because the loss of function, spanning several years, had progressed slowly.

The informants who explicitly stated to have impaired masticatory ability had one thing in common. They had experienced a sudden and drastic change in masticatory ability, often because of dental treatment that involved extraction of multiple teeth or due to prosthodontic failure.

4.4 STUDY III

Out of 544 subjects, $n = 99$ (18.2%) participated in all the follow-ups, 44 (8.1%) participated in at least two follow-ups, 1 (0.2%) participated only at study entry. 400 participants (73.5%) died during this period. They were divided into three categories, *A*, *B* and *C*, according to the Eichner index. See Table 7. Participants in Eichner categories *B* and *C* were older and had lower educational level compared to those in category *A*. Use of dentures and periodontal disease was also more prevalent in Eichner category *C*.

Compared to Eichner index category *A* performance in all cognitive domains were lower for *B* and *C*, except for verbal ability which was only significantly different between category *A* and *C*.

When adjusted for sex, education, birth cohort, and practice effects, those in category *B* had a lower performance in verbal ability at intercept compared to *A*. The participants in category *B* and *C* also had a steeper decline in spatial/fluid abilities after age 65. There was no significant difference between Eichner category *A* relative to *B* or *C* in the intercept or slopes for perceptual speed, memory or the cognitive component score. After further adjustment for hypertension, heart disease, periodontal disease, prosthesis use, childhood SES, and alcohol consumption, the association between Eichner category *B* and verbal ability intercept remained significant, as did the association between Eichner category *B* and *C* with spatial/fluid abilities.

During follow-up time 52 out of the 544 (9.6%) participants developed dementia. In crude and adjusted Cox regression models, estimates did not indicate higher dementia risk for participants in Eichner categories *B* and *C* compared to Eichner *A*.

Table 7

Eichner index	A n=147 (27.0%)	B n= 169 (31.1%)	C n= 228 (41.9%)	p value
Age /years	60.1 (± 7.9)	64.6 (± 8.3) ^a	69.9 (± 7.6) ^{a,b}	<0.001
Female sex	80 (54.4)	98 (58.0)	136 (59.7)	0.604
Education				
Low	59 (40.7)	98 (60.1) ^a	172 (77.5) ^{a,b}	<0.001
High	86 (59.3)	65 (39.9) ^a	50 (22.5) ^{a,b}	
Hypertension	54 (36.7)	80 (47.3)	121 (53.1) ^a	0.008
Heart disease	10 (6.8)	21 (12.6)	43 (18.9) ^a	0.004
Diabetes	7 (4.8)	13 (7.7)	20 (8.8)	0.341
Cerebrovascular disease	0 (0.0)	3 (1.9)	4 (2.0)=	0.254
Any APOE $\epsilon 4$	43 (31.6)	44 (28.6)	63 (31.3)	0.812
BMI (kg/m ²)	25.0 (± 3.6)	25.8 (± 4.5)	25.9 (± 3.8)	0.105
Smokers	71 (48.0)	73 (42.0)	109 (43.8)	0.631
Current	37 (25.9)	33 (20.0)	56 (25.3)	
Past	34 (23.8)	37 (22.4)	46 (20.8)	
Never	72 (50.4)	95 (57.6)	119 (53.9)	
Alcohol drinkers	135 (91.8)	142 (84.0)	177 (77.6)	0.001
Childhood SES	0.6 (± 2.6)	-0.1 (± 2.3)	-0.7 (± 2.2)	<0.001
Birth cohort				
Early born 1886-1925	46 (31.3)	91 (53.9) ^a	180 (79.0) ^b	<0.001
Late born 1926-1958	101 (68.7)	78 (46.2) ^a	48 (21.1) ^{a*}	
Gingivitis				
No	113 (76.9)	132 (78.1)	192 (85.0)	0.094
Sometimes/Yes	34 (23.1)	37 (21.9)	34 (15.0)	
Periodontitis	14 (9.7)	26 (15.5)	68 (31.9) ^b	<0.001
Dentures				
None	96 (65.3)	83 (49.1) ^a	21 (9.2) ^b	<0.001
Half	0 (0.0)	0 (0.0)	185 (81.1) ^b	
Whole	51 (36.7)	86 (50.9) ^a	22 (9.7) ^b	
Cognitive performance				
Verbal ability	55.0 (± 8.7)	52.5 (± 8.3)	49.2 (± 8.7) ^b	<0.001
Memory	56.03 (± 9.4)	51.5 (± 9.4)	48.8 (± 9.9)	<0.001
Spatial/fluid abilities	56.4 (± 9.4)	51.8 (± 8.0)	47.9 (± 9.2) ^b	<0.001
Perceptual speed	57.2 (± 9.0)	52.3 (± 8.6) ^a	46.5 (± 9.2) ^b	<0.001
General cognitive score ^c	57.5 (± 9.1)	52.6 (± 7.9) ^a	47.2 (± 9.0) ^b	<0.001

Table 7. Abbreviations: BMI= Body Mass Index, APOE=apolipoprotein, SES= Socioeconomic status Data n=(%) or mean (\pm SD), ^a Bonferroni pairwise comparison (reference Eichner Index A), ^b Significant difference Eichner Index B vs C.

4.5 STUDY IV

Out of the 355 individuals, a total of 196 individuals met the age requirement of 60 years or older and were included in the present study. Of these, 110 (56%) participants did not have the cognitive ability to answer the MA-related questions (Q⁰). The subjects in this group were older, had fewer occlusal contacts and proportionally denture use was more prevalent. 86 (44%) filled in the questionnaires, see Table 8.

The participants in group Q0 tended to be assessed as at risk of malnutrition and as malnourished compared with the subjects in group Q1, however the difference was not statistically significant. Low CC was also more prevalent in group Q0 and there was a significant difference between Q1 and Q0 concerning the Eichner index, $p = 0.03$ as well as the total MNA score, $p = 0.016$.

Table 8.

Characteristics	Participants n=196	Answered Questionnaire n = 86 Group Q ¹	Not Answered Questionnaire n = 110 Group Q ⁰
Age (yrs) mean \pm SD	79.7 \pm 10.8	76.7 \pm 11.4	81.7 \pm 9.8
Female/male, n (%)	119/77 (61/39)	51/35 (59/41)	68/42 (62/38)
Dentures, n (%)	88 (45)	37 (42)	51 (63)
^a Eichner index group			
A, n	32	20	22
B, n	66	31	35
C, n	98	35	63
^b MNA (0–30 p) median, range	23, 14.5	24, 14	21.6, 13.5
Normal 24–30 p, n (%)	87 (45)	47 (55)	40 (37)
At risk 17–23.5 p, n (%)	88 (45)	34 (40)	54 (49)
Malnourished < 17 p, n (%)	19 (10)	4 (5)	15 (14)
BMI < 21 n (%)	15 (9)	2 (2)	13 (12)
BMI > 21 n (%)	176 (91)	79 (98)	97 (88)
CC < 31 cm, n (%)	35 (18)	8 (9)	27 (25)
CC \geq 31 cm, n (%)	159 (82)	78 (91)	81 (75)
MAC < 21 cm, n (%)	1 (1)	1 (1)	0 (0)
MAC = 21–22 cm, n (%)	7 (4)	1 (1)	6 (5)
MAC > 22 cm, n (%)	187 (95)	84 (98)	103 (95)
Mode of feeding: Need assistance/self-fed with difficulty/self-fed	16/23/157	2/3/83	14/20/74

Characteristics of study population Study IV

4.5.1.1 *Masticatory performance and Masticatory ability*

There was a trend towards a positive relationship between MP and MA, though this relationship was not statistically significant. Eighty-eight percent of those in Eichner A group reported that they never/seldom had to limit the kind or amounts of food they eat because of problems with their teeth or dentures, compared to B (81%) and C (77%) groups.

Furthermore, no significant statistical relationship was found between the Eichner index with and without dentures.

In Eichner group A 93% answered “*never/seldom*” to the question “*How often did you limit the kinds or amounts of food you eat because of problems with your teeth or dentures?*” compared to 80% and 79% in group B and C respectively. Similarly, 90% of those belonging to group A rated their ability to chew solid food to be “good,” as compared to 77% in group C.

4.5.1.2 *3.2. Masticatory Performance and Nutritional Variables*

No significant relationship was found between the Eichner index and total MNA score ($p = 0.704$) or CC ($p = 0.810$) and MAC ($p = 0.590$). However, a significant relationship was found between BMI and Eichner index where prosthetic occluding contact were excluded (no denture) BMI, X^2 ($N = 191$), $p = 0.015$.

4.5.1.3 *Masticatory ability and Nutritional Variables*

No possible relationships between the items from the questionnaires and any of the nutritional items, were found.

5 DISCUSSION

5.1 MEASUREMENTS TO ASSESS MASTICATORY PERFORMANCE

Methods to assess MP have been developed primarily for scientific and experimental reasons and not in a general setting as a diagnostic tool, however in recent years effort have been made to make some of these methods less practically cumbersome (72-75). Still there is no established method to assess MP in a clinical setting.

5.1.1 Construct validity

Construct validity concerns to which extent a measurement or test assesses the construct it supposes to measure (61). This can be assessed by formulating a specific hypothesis on how the measurement will perform in relation to for example clinical variables or other instruments. In a majority of the included studies assessing construct validity few hypotheses were thoroughly stated or formulated.

Our systematic review reported moderate to strong level of evidence for construct validity concerning two colour chewing gum or wax and digital software analysis. However limited level of evidence was reported for commination, gummy-jelly, and fuchsin beads. This does not necessarily mean that the methods are not valid. The methods generally received poor methodological grades because they were not explicably described according to the COSMIN checklist.

5.1.2 Reliability and Measurement error

Reliability is by COSMIN as: *The extent to which scores for patients who have not changed are the same for repeated measurement under several conditions.* Are the measurement consistent over time (test-retest); or by when measured by different persons on the same occasion (inter-rater); or by the same persons (raters) on different occasions (intra-rater). Generally, the methodological quality of the studies assessing this measurement property were considered to at least adequate.

Measurement error was evaluated in a few studies. In a scientific setting reliability can perhaps be considered more of interest than in a clinical or diagnostic context, where the clinician is more concerned with a single patient. It was clear from the results of our review that measurement error was not considered to the same degree as reliability as only five studies assessed this measurement property. Since these different methods were evaluated for scientific purposes this could explain the lack of measurement error assessments. Also, to assess measurement error *minimal important change* (MIC), the smallest change measured in

a measurement that is perceived to be clinically important, must be stated which could be hard to define in a method assessing MP. Some studies that evaluated reliability used intra class correlation coefficient (ICC) and from these formulas' measurement error can be derived, however these were not clearly stated in the included studies.

Since this systematic review was published more literature has been published evaluating measurement properties of previously published measurement methods (76-78) and new methods have also been evaluated (79-81).

The hope for Study I was to identify a possible and valid method to assess MP for further studies in a clinical setting, but few methods were identified that could practically be used for further clinical studies.

5.2 MASTICATORY ABILITY IN OLDER INDIVIDUALS – A PROCESS OF ADAPTATION

Study II showed that many of the informants assessed their ability to masticate food to be good, without the need to adjust their eating habits. However, when asked further and the informants had to more deeply reflect on how their MA had changed throughout life, they realized that they had indeed adapted to a functional loss and that they had at first overrated their ability to masticate. Since the difference in chewing efficiency between dentate and denture wearers is obvious (82) it would be presumed that these individuals overrate their MA as they adapt by eating more easily masticated food.

A similar trend could be seen in Study IV where 79% of the participants who had no functional occluding contacts rated their MA to be *good* and 77% claimed that they did not have to alter their choice of food because of hampered masticatory function. Most of these individuals used dentures and from a clinical and scientific perspective it would be hard to accept that these participants would be able to masticate just as good as those who had fully occluding tooth contacts in Eichner group A, especially since studies have shown that denture wearers have to chew more (18, 83, 84) and have a decreased bite force (85) compared to dentate individuals.

Johansson et al. showed that MA decreases with age, despite only minor changes in dental status (86) and improved dental state, through for example prosthetic rehabilitation, MA exhibits only minor variation over time (87). A possible explanation for this could be that MA involves other facets, such as adaptation, dietary habits, psychological and cultural aspects, that cannot be obtained from objective and functional tests. What also needs to be considered is whether questionnaire items concerning MA can be adequately used in a

population in which individuals are dependent on supportive care, both for medical and cognitive reasons.

MA is useful when evaluating patient satisfaction or OHRQoL, but it should be used with caution when assessing masticatory function and other health related aspects such as nutrition and cognition.

5.3 MASTICATORY FUNCTION AND COGNITIVE FUNCTION – A LONGITUDINAL PERSPECTIVE

A number of published systematic reviews and meta analyses have examined the relationship between oral health and cognitive status (88-90), however the current level of evidence is still limited (91).

A prospective study including 991 individuals followed through a period of eight years showed that complete tooth loss was significantly associated with lower cognitive performance. However, neither number of teeth nor edentulism predicted greater subsequent cognitive decline (92). Another study reported that a tooth loss of more than 11 teeth was associated with a lower risk of dementia in participants with lower education (93). The conclusions from these meta-analyses have been either that the evidence is limited, inconclusive, or that poor oral health is a risk factor for cognitive impairment.

In Study III our results showed that having more posterior contacts assessed, with Eichner index, was associated with better cognitive abilities. However, no consideration was taken to whether these occluding pairs were included real teeth or prosthetic teeth. An assessment of MP with an experimental test food would have been a better assessment of objective masticatory function but this data was not available.

In Study III, we found baseline associations between Eichner categories and verbal ability, however, masticatory function did not predict decline in verbal ability. No link could be found between masticatory function and memory which could be explained by reverse causality, that pre-clinical cognitive impairment can lead to poor oral hygiene and subsequently poor oral health. In Study III we found an association between occlusal support and spatial/fluid ability. Spatial memory is an aspect of memory regarding one's environment and spatial orientation (94). These results are in line with a human experimental cross-sectional study where increased chewing led to increased efficiency in the executive networks and function (95) .

Study III did not find the number of occluding contacts to be associated with a higher risk of dementia. However, the participants categorized into the Eichner group C were, on average, 10 years older than those in group A and showed overall poorer general health and had the highest proportions of death and therefore the individuals with poorest masticatory function perhaps did not live long enough to develop diagnostic manifestations of dementia. Our results are in line with a Japanese study involving a possible link between oral health dementia onset (96).

Study III could not indicate a link between number of occluding contacts and risk of dementia onset, but the literature has shown conflicting results. A problem is the methodological considerations when assessing masticatory function since different studies use different methods to assess masticatory function. Some use self-reported masticatory ability, while others, like Study III of this thesis, use clinical data like Eicher index and a few use more experimental objective measurement like masticatory performance (97). There is also a lack of intervention studies that could indicate a possible causal relationship.

5.4 ORAL FUNCTION AND GENERAL HEALTH AT OLD AGE

Loss of teeth and declined masticatory function has been shown to be associated with adverse health-related outcomes, associated with mortality, physical frailty, functional disability, hospitalization, and falls (98).

5.4.1 Masticatory performance, masticatory ability and nutritional status

The relationship between MP and MA is not yet defined (13) especially in older individuals (14, 99). Some studies show a positive relationship (100) while others have not been able to verify such an association (101). In Study IV we could not find such a link between subjective assessment and the number of occluding tooth contacts. The edentulous patients, who often used removable full dentures, generally presented a positive view of their MA. This is in line with the results from Study II where the participants at first tended to overrate their MA.

Similarly, no statistical relationship between MP, MA and any of the nutritional variables were found. The body of published literature report conflicting results when it comes to MF and nutrition. Some report an association between objective masticatory variables and nutrition, either for MP (55, 102, 103) or MA (25) while others have not found such link or conflicting results for MP (29, 99, 104, 105) or MA. There could be a discrepancy in the results since the study populations differ between studies. Fujimoto et al. found a strong

positive relationship between MA and nutritional status in an older population who received dental maintenance treatment at an outpatient clinic (99).

The study population in Study IV consisted mainly of individuals who lived in nursing homes or group housings, and the lack of association between MP or MA and nutritional status is in accordance with other published literature concerning care dependent older individuals (106). There could be a general discrepancy between community-dwelling and nursing home residents concerning nutritional status.

5.5 METHODOLOGICAL CONSIDERATIONS AND GENERALISABILITY OF THE STUDIES

To be useful in clinical practice, clinical studies need to produce results that are generalisable to a wider population. The studies need to be replicated and repeated in order to confirm that the results are consistent. It is also important that the results are interpreted adequately.

Internal validity is the extent to which an observed association supports the hypothesis of cause and effect and that the testing is not influenced by other variables. The validity of the measurements is also an important component. External validity concerns whether the results identified in the study population can be generalized to a general population (107).

5.5.1 Study I

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) have produced guidelines for reporting systematic reviews also known as the PRISMA statement (108) and although it focuses on RCTs, these guidelines were followed to the extent it was applicable during the methodological development of Study I. The COSMIN group states that a systematic review at least has to give information on these issues: results of the literature search and selection of studies; methodological quality of the included studies; characteristics of included measurement instruments; characteristics of the included study populations; adequacy and results of the measurement properties and the conclusion of the best measurement instrument (61).

In accordance with these guidelines the work began with a study protocol that was peer-reviewed and published prior to when work started with Study I (109). The search string was published and the results from the literature search was presented in flow-chart according to PRISMA. The methodological quality for each measurement property and characteristic included methods were presented in tables according to the guidance of the COSMIN group. The results of each measurement property was also presented separately for transparency

reasons and an overall score, which integrated quality of the evidence on each measurement property with the results of the study, was presented in a separate table.

Since Study 1 was published the COSMIN group have developed new tools to assess the measurement properties *reliability* and *measurement error* of performance-based tests or clinician-reported outcome measures which are more suitable for these types of tests and would have been beneficial to use in this thesis if it would have been available at the time (110).

Studies not published in full text or English were excluded in Study I because of the lack of means to translate identified studies. For instance, a number of studies have been published in Japanese but were not included in the systematic review. Thus, additional information on descriptions of methods for assessing masticatory performance and measurement properties were probably missed that potentially may have affected the level of evidence for different methods.

5.5.2 Study II

5.5.2.1 Internal validity

The interviewer should be able to ask relevant questions but also to be looked upon as a credible person by the participants. The interviewer, it was believed, would be more objective in the approach if not involved in the design of the research process.

The quality criteria for qualitative research are credibility, transferability, dependability and confirmability(111, 112). The term trustworthiness asks the question of whether “the findings can be trusted”(112). To ensure credibility, various strategies can be used in qualitative research. The interview guide helped the interviewer to keep the discussion focused on the topic at hand and used open questions concerning masticatory ability and other oral health related topics. The raw, transcribed data were analysed continuously until a core category emerged.

All three authors were involved in the methodological design and data analysis process to ensure investigator triangulation. Through regular team meetings consensus was achieved on the interpretation of the data with all three researchers. Codes, categories and theoretical saturation were also discussed. The data were reanalyzed, to achieve consistent observations several times through a process in which labels and categories were relabeled until an underlying pattern became visible.

The transferability of Study II can only be assessed by its readers. This is only possible if the research process is described well enough so that readers can make credible assumptions of its transferability to other contexts. Since the participants were allowed to speak freely about the subject, it can therefore be difficult to replicate the results since the information provided are subjective perceptions.

5.5.2.2 External validity

The goal of qualitative research is contextualized understanding of human experience through the intensive study of particular cases(111). In quantitative research random sampling is central to be able to generalize the results from a statistical model, but in qualitative research more selective and purposeful sampling is used to have a representable sample from the study population. The conventional generalizability that is required of the quantitative research cannot be achieved in qualitative research, since qualitative research is conducted on a particular set of population that has their own unique demographic, psychological, sociological, and cultural characteristics. Qualitative research aims to provide an in-depth understanding of contextualized human experiences (112) but its results are not generalisable in the same way as in quantitative research. The aim of Study II was to use the methodological aspects of quantitative research to generate new hypothesis regarding MA and give an in-depth look of the phenomenon, but its results cannot be generalised to a population.

5.5.3 Study III

5.5.3.1 External validity

SATSA includes twins from all parts of Sweden. Since the dental care and health has improved in the last fifty years in Sweden, the transferability to populations growing older today might be limited and the difference might be even bigger compared to international populations.

5.5.3.2 Internal validity

The Eichner index as a measurement of masticatory function could be questioned, however studies have shown that the number of occluding contacts and bite force are the key determinants for MP (15-17), and therefore it was used as an indicator of masticatory function. However, it would have been beneficial to also include bite force in the statistical analysis, but this data was not available. Also, the dental examination during the IPT was conducted by nurses and not dental professionals which is not ideal since they do not have the

same experiences of dental diagnostics, and therefore a greater systematic error must be considered.

5.5.4 Study IV

5.5.4.1 External validity

The study material originates from a population with eligibility to subsidized oral and dental care, administered by the Swedish counties. The individuals all have in common that they are dependent on support with daily living. Region Norrbotten has considerable distances between the municipalities and lack of access to dental care. Possibly the study group had to manage oral problems already in younger ages. They may in higher degree suffer from impaired oral health and tooth loss compared to other parts of Sweden but in a global perspective their situation is not uncommon.

5.5.4.2 Internal validity

In study IV nutritional data that was collected by MNA score, CC, MAC and BMI. It could be argued that these variables by themselves, used independently in analysis, are not a good assessment of nutritional status and to evaluate body composition requires an understanding the strength and weaknesses of each method (113).

The short form of MNA is the most used tool used for nutritional screening in older people. In this thesis the full scale MNA was used which has been extensively tested for validity and reliability (114-116). BMI describes the relation between weight and stature, $BMI = \text{weight (kg)} / \text{height squared (m}^2\text{)}$ and is a commonly used in several screening tools (117, 118) and has been correlated to MNA but has been shown to overestimate nutritional status in geriatric patients who are well nourished and underestimate it those who are at risk of malnutrition(119). There is also no real consensus for optimal BMI for older individuals and different cut-offs for malnutrition have been proposed, MNA for instance uses different cut-off point compared to other nutritional screening tools (120). According to the Global Leadership for Malnutrition (GLIM) criteria for screening and diagnosis of malnutrition the cut-off for BMI in individuals >70 years is 22 (121). BMI does not discriminate between fat or muscle mass. In study IV BMI tended to be lower in the Eichner group B, compared to

both A and C. It could be argued that those individuals in group C, without any occluding support would be given more easily masticated and energy rich food which could explain higher BMI in group C compared to B.

CC and MAC are easy methods to apply in a clinical context, requiring only a measure tape. MAC has however been found to be a poor marker for malnutrition(122) and CC is limited by cofounding factors such as edema. One of the difficulties of encountered in Study IV was how valid the collected nutritional data were as indicators of nutritional status and if they were adequate variables to use in statistical analysis to explore a possible relationship between MF and nutrition. There is a lack of consensus on diagnostic criteria for malnutrition in a clinical context.

The Eichner index was also used in Study IV and its limitation have been discussed previously. Unlike Study III, in Study the dental examination and data collection was conducted by dental professionals.

6 CONCLUSIONS

Methods to assess masticatory performance are often labor intensive and not fitted to a clinical setting. Older individuals with at deteriorating oral function tend to overrate their masticatory ability and self-reported questionnaires seem less useful. With the chosen instruments in this thesis, a low number of occluding contacts was not associated to an increased risk of dementia or nutritional variables. Further research is needed to find masticatory measurement methods, that are useful both in clinical contexts and research.

The four studies forming this thesis suggest that:

Study I: No established method for assessing masticatory performance was identified with a strong level of evidence for all measurement properties, however in recent years new methods have been developed that have assessed measurement properties and tried to replicate previous results.

Study II: Older individuals with a deteriorating oral function cope through a process of adaptation which includes lifestyle changes. Oral rehabilitation to improve masticatory function does not necessarily improve dietary habits and therefore a multidisciplinary approach should be considered.

Study III: A low number of occluding contacts was not associated to with an increased risk of dementia; however it was associated with increased cognitive decline in spatial/fluid abilities.

Study IV: No significant associations could be found between the different masticatory sub-domains or any of the nutritional variables. Self-reported questionnaires seem less useful among older care dependent individuals.

7 POINTS OF PERSPECTIVE

This thesis includes many different study designs and methodologies with different approaches to study masticatory function in older individuals. There are many different ways to assess MP in a laboratory environment, although few of these methods have made an entry in daily clinical practice. For both practitioners and researchers working in geriatric dentistry it would be beneficial to have an established and standardized method to use in a clinical context.

Subjective self-reporting of masticatory ability is an important variable for OHRQoL but it should be used carefully in relation to other variables. An objective assessment of masticatory function does not necessarily correlate with an older individuals subjective assessment. Therefore, dental professionals in geriatric dentistry should consider that improved oral function through oral rehabilitation, does not necessarily result in changed dietary and nutritional habits.

With regards to the association between masticatory function and cognitive function the results from the published body of literature is contradictory. This can partly be explained by the lack of consensus of which aspect of MF that should be used in these types of studies and the different methods used to assess these aspects. It would be beneficial if future studies would conform in both measurement methodology and what aspect of MF they assess. Beside this, since observational studies are limited to establish significant associations and not cause-and-effect, the next step for future research concerning this topic would be intervention studies to assess if there is a real causal relationship.

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10 APPENDICES

Appendix 1.

1.

Documentation of search strategies

University Library search consultation group

Date: January 2017

Topic/research question: Methods for objectively assessing clinical masticatory performance

Name of researcher(s): Per Stjernfeldt-Elgestad, Department of Dental Medicine

Librarian(s): Carl Gornitzki & Susanne Gustafsson

Databases:

1. Medline (Ovid)
 2. Embase (embase.com)
 3. Web of Science Core Collection
 4. Cochrane Library (Wiley)
 5. ...
-

Total number of hits:

- Before deduplication:
 - After deduplication:
-

Comments:

2. Embase (embase.com)

Date of Search: 2017-01-26	Field labels:
Number of hits: 4,746	
Comments:	

<p>#1 'mastication'/de</p> <p>#2 masticat*:ti,ab OR 'oral function':ti,ab OR chewed:ti,ab OR chewing:ti,ab OR 'bite force':ti,ab OR dentition*:ti,ab OR denture*:ti,ab</p> <p>#3 #1 OR #2</p> <p>#4 'chewing gum'/de</p> <p>#5 'swallowing'/de</p> <p>#6 'food'/exp</p> <p>#7 sieving:ti,ab OR sieve:ti,ab OR comminution:ti,ab OR swallow*:ti,ab OR saliva*:ti,ab OR gum:ti,ab OR jell*:ti,ab OR wax:ti,ab OR food:ti,ab</p> <p>#8 #4 OR #5 OR #6 OR #7</p> <p>#9 'psychologic test'/de</p> <p>#10 'neuropsychological test'/de</p> <p>#11 'health status indicator'/de</p> <p>#12 'severity of illness index'/de</p> <p>#13 'karnofsky performance status'/de</p> <p>#14 'sickness impact profile'/de</p> <p>#15 'psychometry'/de</p> <p>#16 'reproducibility'/de</p> <p>#17 measur*:ti,ab OR assess*:ti,ab OR evaluat*:ti,ab OR test*:ti,ab OR inventor*:ti,ab OR battery:ti,ab OR indicator*:ti,ab OR profile:ti,ab OR index:ti,ab OR indices:ti,ab OR scale*:ti,ab OR instrument*:ti,ab OR psychometric*:ti,ab OR reproduc*:ti,ab OR reliable:ti,ab OR reliability:ti,ab OR valid*:ti,ab</p> <p>#18 #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17</p>

#19 #3 AND #8 AND #18

#20 #3 AND #8 AND #18 AND [english]/lim

#21 [animals]/lim NOT [humans]/lim

#22 #20 NOT #21

#23 #22 AND ('article'/it OR 'article in press'/it OR 'conference paper'/it OR 'review'/it)

5. Cinahl (Ebsco)

Date of Search: 2017-01-26		Field labels:
Number of hits:		
Comments:		
#	Query	Results
S1	(MH "Mastication")	987
S2	(MH "Bite Force")	396
S3	TI (masticat* OR "oral function" OR chewed OR chewing OR "bite force" OR dentition* OR denture*) OR AB (masticat* OR "oral function" OR chewed OR chewing OR "bite force" OR dentition* OR denture*)	5,248
S4	S1 OR S2 OR S3	5,707
S5	(MH "Chewing Gum")	499
S6	(MH "Deglutition")	1,928
S7	(MH "Deglutition Disorders")	4,027
S8	(MH "Food+")	77,464
S9	TI (sieving OR sieve OR comminution OR swallow* OR saliva* OR gum OR jell* OR wax OR food) OR AB (sieving OR sieve OR comminution OR swallow* OR saliva* OR gum OR jell* OR wax OR food)	48,792
S10	S5 OR S6 OR S7 OR S8 OR S9	116,002

S11	(MH "Psychological Tests")	44,713
S12	(MH "Neuropsychological Tests")	18,778
S13	(MH "Health Status Indicators")	7,099
S14	(MH "Severity of Illness Indices+")	25,430
S15	(MH "Karnofsky Performance Status")	1,020
S16	(MH "Sickness Impact Profile")	1,217
S17	(MH "Psychometrics")	9,313
S18	(MH "Reproducibility of Results")	16,820
S19	TI (measur* OR assess* OR evaluat* OR test* OR inventor* OR battery OR indicator* OR profile OR index OR indices OR scale* OR instrument* OR psychometric* OR reproduc* OR reliable OR reliability OR valid*) OR AB (measur* OR assess* OR evaluat* OR test* OR inventor* OR battery OR indicator* OR profile OR index OR indices OR scale* OR instrument* OR psychometric* OR reproduc* OR reliable OR reliability OR valid*)	833,081
S20	S11 OR S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19	867,277
S21	S3 AND S10 AND S20	737
S22	S3 AND S10 AND S20	730

S23	S3 AND S10 AND S20	622
S24	S3 AND S10 AND S20	730

Appendix 2

Comminution tests			
Study, first author	Study objective	Measurement property	Methodological quality/Quality of measurement property
Khoury-Ribas 2017	Assessment of Optosil Plus® & sieve as a method to assess MP. Optozeta as a test food compared with Optosil.	Validity (hypotheses testing) Reliability	Poor/Positive Poor/Negative
Sanchez-Ayala 2016	Evaluation of encapsulated fuchsine beads as a method to assess MP.	Validity (criterion validity) Reliability, measurement error.	Good/Negative Good/Indeterminate
Eberhard et al (2015)	Comparison of optical scanning of fragmented test food particles to sieve method w/ 10 sieves.	Validity (criterion validity)	Poor/Positive
Nokubi 2013	Assessment of a visual scoring scale, 1-10, to assess MP w/ Gummy jelly as test food.	Validity (hypotheses testing), Reliability	Fair/Positive Good/Positive
Sanchez-Ayala 2014	Assessment of Optosil Comfort® as an artificial test food for MP evaluation using sieve method	Reliability	Good/Positive
Eberhard 2012	Comparison of optical scanning of fragmented test food particles to sieve method with 10 sieves.	Validity (criterion validity)	Poor/Positive

Woda 2010	Assessment of MP w/ Masticatory normative indicator.	Validity (hypotheses testing)	Poor/positive
Fauzza 2008	Assessment of alginate as a test food to assess MP in denture wearers.	Responsiveness	Poor/Indeterminate
Felicio 2008	Evaluation of encapsulated fuchsine beads as a method to assess MP.	Validity (hypotheses testing), Reliability.	Poor/positive Poor/Indeterminate
Lujan-Climent 2008	Assessment of Optosil Plus® sieve as a method to assess MP.	Reliability Measurement error	Poor/Positive Poor/Indeterminate
Escudeiro Santos 2006	Evaluation of encapsulated fuchsine beads as a method to assess MP	Validity (hypotheses testing) Reliability	Poor/Positive Poor/Indeterminate
Ikebe 2006	Evaluation of gummy jelly as a test food to assess MP.	Validity (hypothesis testing)	Poor/Positive
Kobayashi 2006	Evaluation of gummy jelly as a test food to assess MP.	Validity (criterion validity)	Poor/Positive
Shiga 2006	Assessment of MP with gummy jelly as test food and blood glucose meter to measure glucose concentration released after chewing	Validity (hypothesis testing)	Poor/Positive
O'Hara 2003	Assessment of alginate as a test food & sieve method to assess MP.	Validity (hypotheses testing), Reliability	Poor/Positive Fair/Negative

Huggare 1997	Evaluation of color binding tablets to assess MP. Dye concentration. Measured with spectrophotometer	Validity (hypotheses testing), Reliability	Poor/Positive Poor/Indeterminate
Mowlana 1994	Assessment of optical scanning as a method to analyze fragmented test food particles, using flatbed scanner & digital image software.	Validity (hypotheses testing)	Poor/Indeterminate
Slagter 1993	Comparison of Optocal & Optosil as a test food w/ sieve test.	Validity (hypotheses testing),	Poor/Positive
Mahmood 1992	Assessment of an image analyzer, Magiscan 2, as a method to analyze fragmented test food.	Validity (hypotheses testing), Responsiveness Reliability	Fair/Negative Poor/Negative Poor/Indeterminate
Gunne 1985	Evaluation of gelatin hardened by formalin as test food to assess MP. Method compared to sieve method with almonds.	Validity (hypotheses testing)	Poor/Indeterminate
Kapur 1964	Assessment of carrot as test food to evaluate MP in dentures wearers. Single sieve.	Reliability	Fair/Positive

Mixing tests			
Study, first author	Study objective	Measurement property	Methodological quality/Quality of measurement property
Silva 2018	Assessment of color mixing w/ w/ color scale & digital image software.	Reliability Measurement error	Good/Positive Good/Indeterminate
Wada 2017	Evaluating Gum XYLITOL & digital image software.	Validity (hypothesis testing)	Fair/Positive
Vaccaro 2016	Assessment of color mixing w/ a digital software on photographed wafer. Gum: Red & white.	Validity (hypotheses testing)	Excellent/Positive
Schimmel 2015	Assessment of color mixing w/ digital software, ViewGum, on scanned wafer. Subjective assessment of gum bolus.	Validity (hypotheses testing), Reliability	Fair/Positive Fair/Positive
Endo 2014	Assessment of color mixing w/ digital software, Adobe Photoshop CS3®, on scanned wafer.	Reliability Measurement error	Poor/Indeterminate Fair/Indeterminate

Hama 2014	Assessment of color change in Masticatory Performance Evaluating Gum XYLITOL to rate MP.	Validity (hypotheses testing) Reliability	Poor/Positive Poor/Positive
Hama 2014	Assessment of MP with color change of gum. Color scale compared with colorimeter and CIELAB color system as golden standard.	Validity (criterion validity), Reliability	Fair/Positive Fair/Positive
Halazonetis 2013	Assessment of color mixing w/ digital software, ViewGum, on scanned wafer.	Validity (hypotheses testing) Measurement error	Poor/Positive Fair/Indeterminate
Weijnenberg 2013	Assessment of color mixing w/ a digital software on photographed wafer.	Validity (hypotheses testing) Reliability	Poor/Negative Poor/Positive
van der Bilt 2012	MP assessed with two colored wax and Mixing Ability Test rated by visual assessment.	Validity (hypothesis testing) Reliability	Good/positive Good/Indeterminate

Abe 2010	2-colored rice & uirou (rice cake) mixing assessed w/ video endoscopic & digital image software.	Validity (hypotheses testing)	Poor/Positive
Kamiyama 2010	Assessment of color scale used to rate color change of Masticatory Performance Evaluating Gum XYLITOL.	Validity (criterion validity) Reliability	Fair/Positive Fair/Positive
van der Bilt 2010	Assessment of color mixing of 2-colored gum w/ digital software.	Validity (hypotheses testing)	Fair/Negative for young test group Fair/Positive for elderly test group
Speksnijder 2009	MP assessed w/ two colored wax & Mixing Ability Test that assesses color mixing.	Validity (hypotheses testing)	Good/Positive
Sugiura 2009	Color mixing/ bolus shape w/ 2-colored wax.	Validity (hypotheses testing), Measurement error.	Good/Positive Good/Indeterminate

Ishikawa 2007	Color change of Masticatory Performance Evaluating Gum XYLITOL Color change assessed w/ colorimeter.	Responsiveness	Poor/Indeterminate
Schimmel 2007	Assessment of color mixing w/ digital software, Adobe Photoshop Elements®, on scanned wafer. Subjective assessment of gum bolus, score 1-5 & assessment of color mixing of flattened gum wafer.	Validity (hypotheses testing), Reliability	Poor/Positive Poor/Negative
Asakawa 2005	Is a two colored wax & the Mixing Ability Index able to detect difference of masticatory function before & after denture treatment?	Responsiveness	Fair/Negative
Sato 2003	Assessment of color mixing & bolus shape & MP evaluated w/ 2-colored wax.	Validity (hypotheses testing), Reliability	Fair/Positive Poor/Positive
Prinz 1999	MP assessed with 2-color chewing gum..	Validity (hypotheses testing)	Poor/Indeterminate

		Measurement error.	Poor/Indeterminate
Hayakawa 1998	Assessment of color changeable chewing gum & color scale for assessment of MP.	Validity (hypotheses testing)	Poor/Positive
Matsui 1996	Evaluation of color changeable chewing gum as a test food to assess MP.	Validity (hypotheses testing), Measurement error	Poor/Indeterminate Poor/Indeterminate
Liedberg 1995	Subjective assessment of color mixing & bolus shaping w/ color scale 1-5, & bolus scale 1-5.	Reliability	Poor/Indeterminate
Other methods			
Study, first author	Study objective	Measurement property	Methodological quality/Quality of measurement property
Goto 2016	Assessment of odour intensity after chewing chewing gum.	Validity (hypotheses testing) Measurement error	Poor/Positive Poor/Indeterminate

Ikebe 2010	Assessment of MP with Eichner index.	Validity (hypotheses testing)	Fair/Positive
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