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RESEARCH

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Use of handgrip strength measurement as an alternative for assessing chewing function in people with dementia

Julia Jockusch^{1,2*}, Sebastian Hahnel³ and Ina Nitschke^{1,4}

Abstract

Background: Chewing ability and handgrip strength can be independent explanatory factors of physical fitness. The usability of measurement procedures for assessing chewing function in people with dementia seems to be limited. This study aimed to show an association between handgrip strength and chewing function to enable the use of handgrip strength measurement as an alternative for determining chewing parameters in people with dementia.

Methods: The data analysed here are part of the OrBiD (Oral Health, Bite Force and Dementia) pilot study. A total of 120 participants were assigned to five evaluation groups based on their cognitive abilities using the Mini-Mental State Examination (MMSE). The MMSE groups in this data analysis were “no dementia” (noDem, MMSE 28–30), “mild cognitive impairment” (mCI, MMSE 25–27), and “mild dementia” (mDem, MMSE 18–24). Handgrip strength, maximum occlusal force, and chewing efficiency were measured.

Results: The Mini-Mental State Examination scores among all participants ($n = 71$) resulted in a median of 27 and a range of 18–30. An association between maximum handgrip strength and the cognitive impairment of the participants was shown. Nevertheless, the use of handgrip strength measurement as an alternative for determining chewing function was not verified in this study.

Conclusions: The feasibility and reliability of chewing function measurements in people with dementia should be investigated. Existing measurement procedures may need to be adapted or new assessments may need to be developed to be usable in people with dementia.

Trial registration: ClinicalTrials.gov NCT03775772.

Keyword: Cognitive impairment, Mini-Mental State Examination, Handgrip strength, Bite force, Chewing efficiency, Measurement, Dementia

Background

Chewing function can be described by the parameters of chewing ability, chewing efficiency, and bite force. Chewing ability (also known as masticatory ability) describes

the subjective chewing ability of a person, which can be determined through questionnaires [1, 2]. Chewing efficiency (also known as masticatory efficiency) refers to objectively measurable chewing performance [3–8]. Bite force (also known as occlusal force or (maximum) occlusal force) is the physiologically possible force used to comminute a chewable item.

Chewing ability can be an independent predictor of physical fitness as measured through activities of daily living (ADL) [9]. Therefore, maintaining oral health,

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which may result in sufficient chewing ability, can improve activities of daily living [9]. It has also been observed that a low chewing ability is associated with lower ADL, lower cognitive functioning, depression, and food insufficiency in older people [10]. Thus, measurement of handgrip strength can be used to draw conclusions about health and physical performance [11].

Several studies have been conducted among community-dwelling older people with intact cognition, showing a relationship between handgrip strength and chewing function (i.e., subjective chewing ability, chewing efficiency, and bite force) [12–15]. It was also shown that participants with a higher body cell mass index (BCMI), higher handgrip strength, and more present teeth (i.e., teeth of the natural dentition (one's own teeth) without taking dentures into account) had a significantly higher chance of achieving strong masseter muscle tension, tested by palpation of the muscle [14]. According to Moriya et al., a relationship might exist between self-assessed chewing ability and muscle strength (recorded as handgrip strength) of the body [16]. Furthermore, chewing efficiency is associated with handgrip strength in older community-dwelling people [15]. The maximum occlusal force (MOF), as a representation of bite force, is strong and independently associated with different measurements of physical performance in men, e.g., handgrip strength [13]. Additionally, different studies with community-dwelling older people showed a correlation between handgrip strength and MOF [17–19] and chewing function [17]. For people with dementia, at present, no studies have examined the relationship between handgrip strength and chewing function (i.e., chewing efficiency and bite force).

As handgrip strength is important for daily activities such as eating (i.e., picking up items) [20], it has been investigated in older people with dementia. Due to its ease in performing the measurement [11], isometric hand dynamometry with the Jamar[®] handheld dynamometer [21] is one of the most commonly used methods to measure muscle strength in people with dementia [22].

Performance-based strength and function measurements are reliable assessment methods in people with dementia. However, functional measurements appear to be more reliable than strength measurements [20]. Nevertheless, the reliability of the Jamar[®] handheld dynamometer is described as excellent in older people with dementia with a Mini-Mental State Examination (MMSE) of 10 to 28 [23], respectively, among those with borderline, mild, and moderate dementia [24].

Several studies have reported on the relationship between general cognition and chewing function in older people with dementia. (e.g., [10, 25]). One study concluded a causal relationship between cognition and

mastication (i.e., chewing efficiency and chewing ability) found in animal and human experimental studies [26]. In a previous evaluation, the authors observed significant differences in chewing efficiencies and bite force between different degrees of cognitive impairment and dementia [27]. Another study reported on the association between chewing ability, tooth loss, and cognitive impairment, observing statistically significant higher odds of cognitive impairment using a self-assessment of older people with dementia [28].

The disability and vulnerability of people with Alzheimer's disease and related dementias [29] who show reduced muscle mass [30] can result in difficulties/an inability to perform motor tasks that require muscular strength [29]. Therefore, it is not surprising that both bite force and handgrip strength [29] are associated with a loss in strength in people with dementia. Additionally, impaired motor skills in people with dementia appear to contribute to reduced chewing efficiency [31].

The use of self-reported information in older people with dementia is questionable due to its reliability [32]; the use of tests for measuring chewing function also have to be questioned. Weijenberg et al. reported a high drop-out rate for the mixing ability test in older people with dementia to assess chewing efficiency [25]. Therefore, the usability of tests of chewing function in people with cognitive impairment or dementia seems to be limited. In the authors' clinical practice, difficulties in conducting tests on bite force and chewing efficiency in people with advanced dementia are apparent due to problems in verbal comprehension, reduced motor skills, and compliance.

Iinuma et al. suggested that decreases in masticatory and skeletal muscle function due to age have mechanisms in common [13]. Perhaps this association can be utilised. In the clinical setting, being able to draw conclusions about chewing function from the measurement of handgrip strength would be helpful.

Because good chewing function is important for maintaining a balanced diet and may, in turn, positively influence body mass index and mortality, more attention should be paid to clinical measurement of chewing function in people with dementia. It has been shown that people without dementia up to mild dementia respond positively to masticatory muscle training [33]. Its effect on nutrition remains to be shown by future studies. Nevertheless, these studies and therapeutic approaches can also benefit people with dementia. However, as people with dementia are often unable to follow complex instructions due to cognitive and motor impairments, it would be of utmost importance for science and clinics to find alternative measurement methods that are feasible

in people with dementia and that allow conclusions to be drawn about chewing function.

The aim of this study was therefore to show a possible association between handgrip strength and bite force, expressed as maximum occlusal force, or chewing efficiency as objective parameters of chewing function. This could enable the use of handgrip strength measurement as an alternative for determining bite force and chewing efficiency in people with cognitive impairment or dementia, in case these measurements are not suitable or feasible.

The authors, therefore, predicted a positive association between handgrip strength and maximum occlusal force as well as handgrip strength and chewing efficiency in people with and without cognitive impairment or dementia, intending to enable the use of handgrip strength measurements as an alternative for the measurement of chewing function.

Methods

Study design

Participants aged 60 years and older who were able to understand German and who were either cognitively healthy, cognitively impaired, or diagnosed with dementia were included in the study. People with all types of dementia could participate in the study. Participants with acute oral processes (pain, abscesses, etc.) that required emergency treatment were not included in the study until the emergency treatment was completed. Participants with physical limitations in the upper body due to musculoskeletal or neuromuscular conditions, e.g., paralysis of the arms, arthritis, post-stroke conditions affecting motor skills, facial nerve paralysis, etc., were excluded from the study. Individuals with additional disabilities which might have had an impact were also excluded (e.g., Trisomy 21, mental disabilities other than cognitive impairment/dementia, etc.).

The data analysed here are part of the OrBiD (Oral Health, Bite Force and Dementia) pilot study (ClinicalTrials.gov NCT03775772) [27, 33–36]. A total of 120 participants were assigned to five evaluation groups based on their cognitive abilities using the MMSE [37]. The MMSE groups in the OrBiD study were “no dementia” (noDem, MMSE 28–30), “mild cognitive impairment” (mCI, MMSE 25–27), “mild dementia” (mDem, MMSE 18–24), “moderate dementia” (modDem, MMSE 10–17), and “severe dementia” (sDem, MMSE \leq 9). The allocation of the MMSE groups was based on the MMSE score categories described by Perneczky et al. [38]. Since the OrBiD study primarily tested the effects of interventions [33, 36] that can be integrated into everyday clinical practice, the authors opted for a slightly modified classification of dementia severity based on participants’ ability to receive

therapy [39] and, associated with this, their ability to participate in assessments and measurement procedures within the study. The basis for setting the thresholds was an expert panel that indicated a range in the MMSE of 16–20 as the threshold for impairment of daily activities [35].

In this analysis, participants with moderate or severe dementia (MMSE \leq 17) were excluded due to observed difficulties in implementing the study instructions when performing the tests for bite force and chewing efficiency. Therefore, the evaluation groups here are noDem, mCI, and mDem.

Data collection

The recruitment process of the participants was adapted due to varied living locations and circumstances, depending on health, cognitive and organisational constraints. A detailed explanation of this process can be found in the literature [35]. Depending on the participants’ mobility, all participants of this analysis were evaluated by one examiner in a geriatric dental clinic or long-term care facilities. The examiner was one dentist with a specialisation in senior dentistry by the German Association of Gerodontology (DGAZ) and experience in senior dentistry and the handling of people with dementia in clinical settings. The study was conducted between September 2017 and June 2019.

Measurements

Sociodemographic data such as age, sex, and living situation (community-dwelling vs. resident of a long-term care facility) were recorded.

The Mini Nutritional Assessment (MNA) [40] consists of a pre-assessment with 6 questions and the main anamnesis containing 12 additional questions with a maximum score of 30 points. A score of 17–23.5 points indicates the participant is at risk of malnutrition. A score of fewer than 17 points indicates poor nutritional status/malnutrition.

The MMSE [37], which tests verbal and non-verbal episodic memory, orientation in time and place, and visual constructive abilities (maximum score 30), was used to assign the participants to the evaluation groups. The MMSE was conducted by one dentist on all participants who did not have a medical diagnosis of dementia and did not provide information on their MMSE score in their requested medical reports.

The measurement of bite force as maximum occlusal force (MOF, in Newton (N)) was performed with the participants in an unsupported, upright sitting position using a GM 10[®] occlusal force meter (Morita, Nagano Keiki, Higashimagome, Ohtaku, Tokyo, Japan) according to the procedure described in the literature

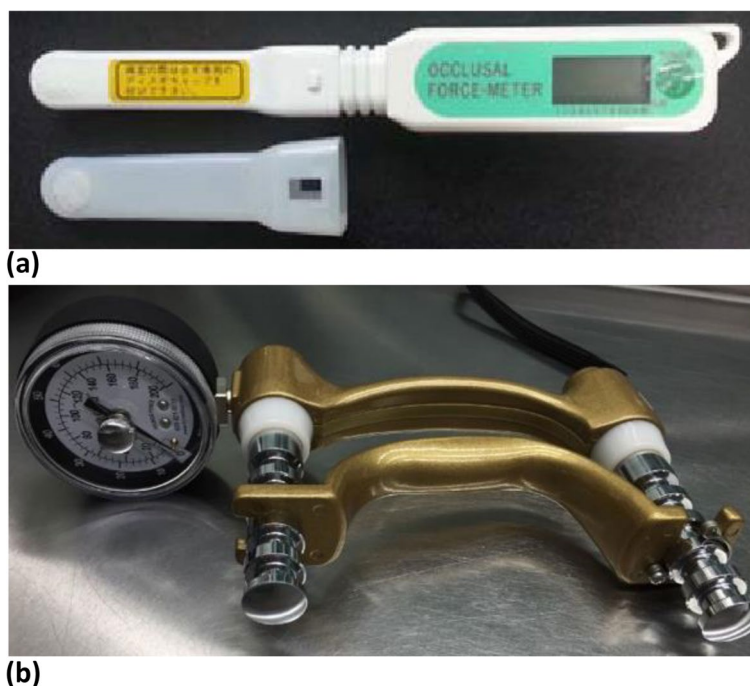


Fig. 1 a Occlusal Force Meter GM 10[®] for measuring the bite force in Newton (N). b Jamar dynamometer

[41] (Fig. 1a). Bite force measurement is performed in the region of the first molar (natural or artificial teeth replaced with bridge or dentures) by applying the maximum possible jaw closing force. When the first molar was missing and not artificially replaced, the measurement was performed at the area closest to the first molar (e.g., second molar/first premolar). Dentures were inserted if available, regardless of the type of denture (complete denture (no own natural teeth present) or partial dentures (partially own teeth present)). The measurement was recorded three times for each side of the jaw. Only the MOF achieved by the participants, which encompassed the maximum measurement of both sides of the jaw, was included in the analysis.

To determine chewing efficiency, the colour-mixing ability test was used as described by Schimmel et al. [8]. The investigator assessed the samples with the subjective visual assessment scale (five-step ordinal subjective assessment scale (SAS) according to Schimmel et al. (2007)) [8]. Additionally, an opto-electronical analysis with the free software ViewGum[®] (www.dhal.com) was carried out, calculating the hue value as a ratio of the unmixed fraction of the chewing gum to the total pixel number in a fixed-size template [42]. The variance of hue (VOH) is a measure of chewing efficiency. Adequate mixing of colours as an expression of good chewing efficiency will result in low VOH and vice versa [8, 42].

Handgrip strength measurement was carried out with the Jamar[®] dynamometer, which has been described as a valid measuring instrument [21, 43]. The participant sits upright on a chair with back support and fixed armrests. Participants are asked to rest their forearms on the arms of the chair and keep their feet flat on the floor. The measuring device is held vertically, with the upper arm suspended in a relaxed position and the forearm angled at 90 degrees. The wrist is slightly bent (about 30 degrees to the forearm). The examiner supports the measuring device from below and instructs the participant to squeeze the grip handle as hard as possible (Fig. 1b).

The participant's hand dominance was recorded but is not analysed here. The measurement of handgrip strength was recorded three times for each hand. The maximum value (in kilogram, kg) of both sides achieved by the participant was included in the analysis as maximum handgrip strength.

The measurement was carried out according to the Southampton protocol [44], but without asking the participant to take off their shoes, as this was not possible for participants in need of care.

Statistical analysis

Since this study was a pilot study, a power calculation was not performed due to the missing description of endpoints in the literature. The sample size was estimated based on similarly designed studies [45, 46].

All statistical analyses and plots were computed with the statistical software R [47], including the packages tidyverse [48], mice [49] and missForest [50], or SPSS 23.0 for descriptive statistics [51]. Missing values were identified and imputed using the missForest algorithm [50].

A descriptive analysis was performed for all the measured parameters (frequencies, median, and range, mean and SD). Graphical tools were used where appropriate to show potential associations between parameters. The Kruskal–Wallis test for independent samples was used to examine whether the independent samples (evaluation groups) differed statistically significantly for the individual parameters examined. The level of significance (α) was set at $p < 0.05$.

Ethical considerations

The data of this analysis are part of a controlled clinical pilot study with interventions and stratified randomisation, called the “Oral Health, Bite Force and Dementia” (OrBiD) study (clinicaltrials.org number: NCT03775772).

The study was approved by the competent Cantonal Ethics Committee (CEC) of Zurich (KEK-ZH 2017–00,363). All participants or their legal representatives gave informed consent.

Results

Study population

A total of 71 participants (age: mean 78.3 years \pm 9.3 years, median 79 years (range 61–95 years), 66.2% female) were included in the analysis. A description of the participants of this analysis regarding their dental and denture status stratified by evaluation group noDem, mCI, and mDem (e.g., number of supporting zones, number of natural teeth, presence, type, and quality of denture) can be found in the literature [27]. Table 1 provides an overview of additional parameters of the participants.

Chewing efficiency, bite force (expressed as maximum occlusal force), and maximum handgrip strength

An association between the VOH and SAS was shown in the analysis, confirming the usability of the colour-mixing ability test according to Schimmel et al. [8] in participants with and without cognitive impairment or dementia. Low VOH values and a high score on the SAS indicate good chewing efficiency (Fig. 2).

The VOH as an expression of chewing efficiency showed only slight—clinically irrelevant—differences between people with mCI and mDem. Overall, no statistical difference in VOH between the evaluation groups was observed (Fig. 3a, Table 1).

The SAS showed almost no differences in the categories SA1 and SA2 (difficulties in enjoying meals [8]) between the evaluation groups noDem and mDem. Participants with mCI demonstrated these degrees of impaired chewing efficiency less often. The opposite of the scale revealed three times more participants with noDem (SA4/SA5: $n=7$, 29.1%) with a good or very good chewing efficiency in terms of the SA categories SA4 and SA5, compared with the evaluation groups mCI (SA4/SA5: $n=3$, 12.5%) or mDem (SA4/SA5: $n=2$, 8.6%). No statistical differences were observed between the evaluation groups for the SAS (Fig. 3b, Table 1) and MOF (Fig. 3c, Table 1).

A statistically significant difference ($p=0.003$, Kruskal–Wallis) in maximum handgrip strength was recorded between the participants with noDem and mDem. Overall, a tendency was observed to show a reduction in maximum handgrip strength with the increase in cognitive impairment (Fig. 3d, Table 1).

Association between handgrip strength and chewing function

Despite the observed association between handgrip strength and cognitive function (Fig. 3d), no association between maximum handgrip strength and the parameters of chewing function (i.e., VOH and MOF) was found in this study (Figs. 4 a and b).

Additionally, no association between maximum handgrip strength and chewing efficiency, visually evaluated with the subjective assessment scale (SAS), was found (Table 2).

Discussion

In this study, an association between VOH and the visual SAS was shown, confirming the usability of the colour-mixing ability test in people with and without cognitive impairment or dementia. A statistically significant difference was also observed between the participants with noDem and mDem for maximum handgrip strength. Overall, a trend was observed showing a reduction in maximum handgrip strength with an increase in cognitive impairment. Nevertheless, associations between handgrip strength and the parameters of chewing function (i.e., chewing efficiency (VOH, SAS) and MOF) could not be proven in this study. The authors’ hypothesis must therefore be rejected.

The study has several limitations. The participants differed not only concerning the MMSE, but also in terms of the living situation (i.e., long-term care facilities and community-dwelling settings). The extent to which place of residence and general living situation can influence the enjoyment of food or the ability to chew was not considered in this study. An older person’s healthy psychological

Table 1 Study parameters stratified by evaluation group

Study parameters	Total <i>n</i> = 71	noDem <i>n</i> = 24	mCI <i>n</i> = 24	mDem <i>n</i> = 23	<i>p</i>
Age [years]					
Mean ± SD	78.3 ± 9.3	74.1 ± 8.3	78.8 ± 10.3	82.2 ± 7.5	0.01
Median (range)	79 (61–95)	75 (62–92)	81 (61–95)	85 (65–95)	
Sex [n/%]					
Male	24/33.8	11/45.8	8/33.3	5/21.7	0.222
Female	47/66.2	13/54.2	16/66.7	18/78.3	
Living situation [n/%]					
Long-term care facility	30/42.3	1/4.2	10/41.7	19/82.6	< 0.001
Community-dwelling	41/57.7	23/95.8	14/58.3	4/17.4	
Mini-Mental State Examination (MMSE)					
Mean ± SD	25.5 ± 3.8	29.1 ± 0.7	26.5 ± 0.7	20.8 ± 2.5	< 0.001
Median (range)	27 (18–30)	29 (28–30)	27 (25–27)	21 (18–24)	
Chewing efficiency					
<i>Variance of hue (VOH)</i>					
Mean ± SD	0.3 ± 0.2	0.3 ± 0.2	0.2 ± 0.2	0.3 ± 0.2	0.522
<i>Subjective assessment scale (SAS) [n/%]</i>					
SA1	10/14.1	3/12.5	3/12.5	4/17.4	0.507
SA2	19/26.8	8/33.3	4/16.7	7/30.4	
SA3	30/42.3	6/25.0	14/58.3	10/43.5	
SA4	7/9.9	5/20.8	1/4.2	1/4.3	
SA5	5/7.0	2/8.3	2/8.3	1/4.3	
Maximum occlusal force (MOF) [kN]					0.282
Mean ± SD	0.2 ± 0.2	0.1 ± 0.2	0.2 ± 0.2	0.1 ± 0.1	
Maximum handgrip strength [kg]					0.003
Mean ± SD					
All participants	21.2 ± 11.1	26.4 ± 10.9	20.7 ± 10.3	16.1 ± 9.8	
Males	31.8 ± 9.7	33.9 ± 11.6	32.3 ± 7.8	26.4 ± 7.0	
Females	15.6 ± 7.0	20 ± 4.5	14.9 ± 5.5	13.2 ± 8.6	
Mini Nutritional Assessment [n/%]	<i>n</i> = 32	<i>n</i> = 7	<i>n</i> = 13	<i>n</i> = 12	
Well-nourished	0/0	0/0	0/0	0/0	0.002
Risk of malnutrition	12/37.5	2/28.6	4/30.8	6/50.0	
Malnutrition	20/62.5	5/71.4	9/69.2	6/50.0	

Bold values in column *p* indicate statistical significance with a significance level of $p < 0.05$, $p =$ Kruskal–Wallis

noDem no dementia, mCI mild cognitive impairment, mDem mild dementia

situation may contribute to a more sustained use of chewing muscles; however, this would require specific investigation.

Differences in age and gender (higher age or higher proportion of women with increasing dementia) can be explained by gender differences in demography.

Other oral factors, such as the number of teeth, the number of occlusal surfaces [52–56], and the type of denture [6, 57–60], can be expected to influence the outcome of masticatory function. They thus have an impact on the observed association between handgrip strength and chewing function as a function of cognitive ability. The authors' original aim was to measure handgrip strength as an alternative to determine the maximum occlusal

force and masticatory efficiency in people with cognitive impairment or dementia, in case these measurement protocols are infeasible. The analysis of this study has only been conducted in this context.

In the literature, a significant relationship between occlusal force and cognition is described after controlling for possible explanatory factors, including handgrip strength as an indicator of general muscle strength, demonstrating oral function independence [61]. The cognitive status of the participants in this study was reported with a mean MoCA-J (Montreal Cognitive Assessment, Japanese version) score of 22.5, which corresponds [62] approximately to the mean MMSE score of 25.5 of all the participants in this analysis. Nevertheless, a comparison

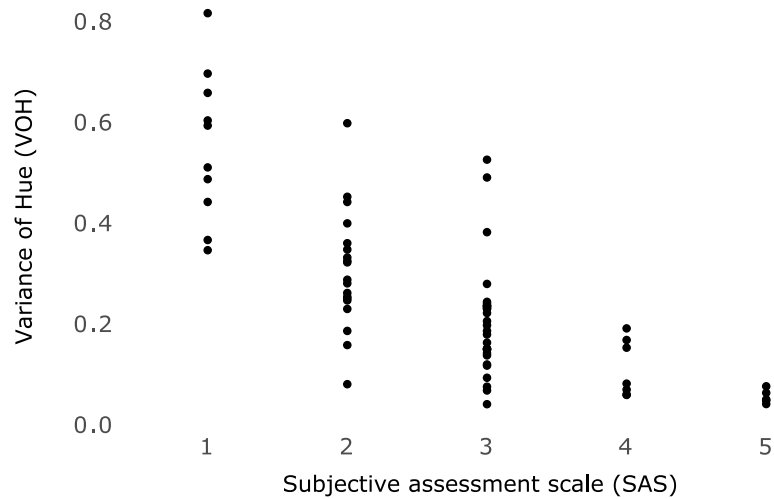


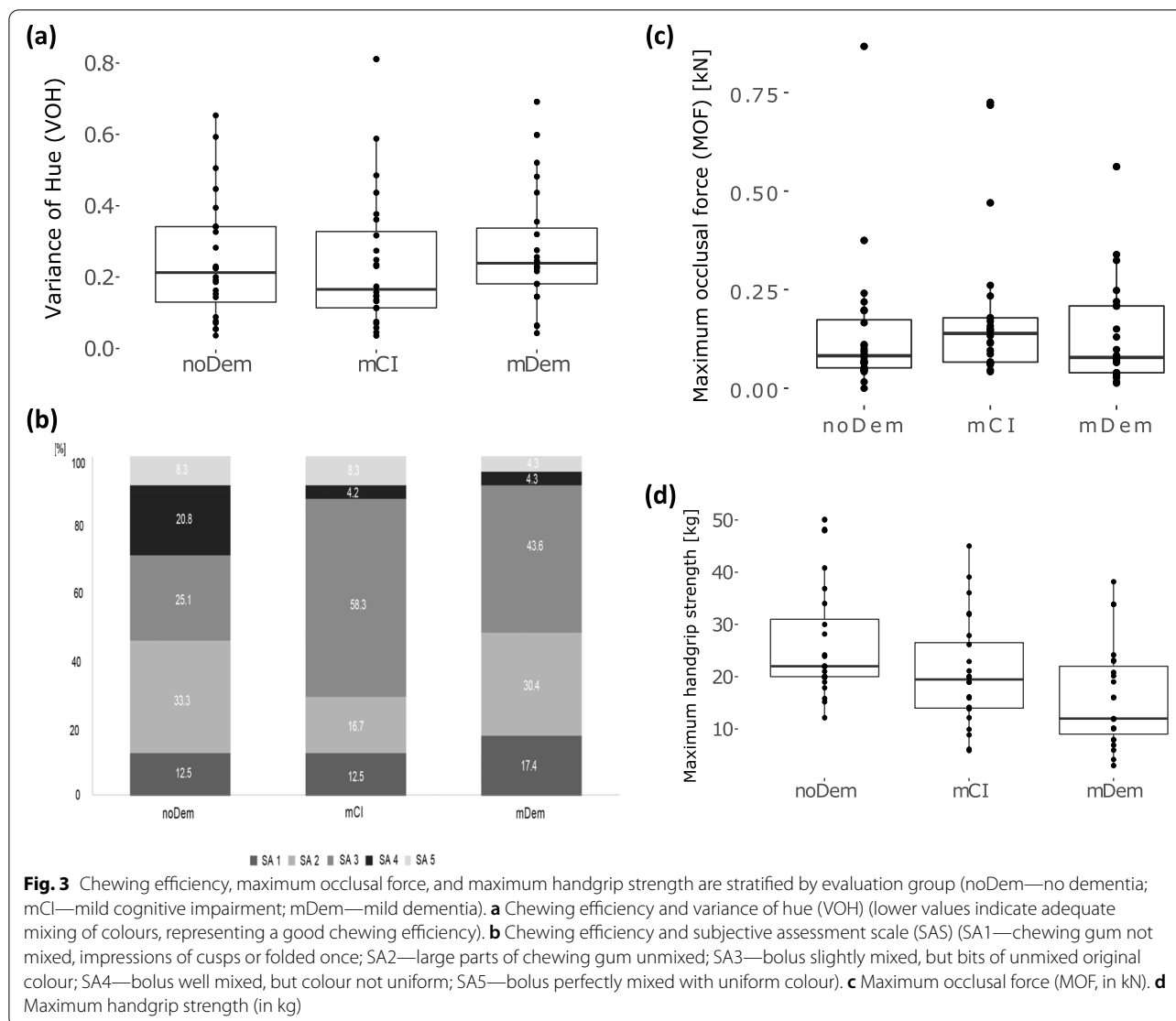
Fig. 2 Dot plot showing the association between the variance of hue (VOH) and the subjective assessment scale (SAS) in people with and without cognitive impairment and/or dementia. (SAS: 5-step ordinal subjective assessment scale. According to Schimmel et al. 2007 [8], SA1—chewing gum not mixed, impressions of cusps or folded once; SA2—large parts of chewing gum unmixed; SA3—bolus slightly mixed, but bits of unmixed original colour; SA4—bolus well mixed, but colour not uniform; SA5—bolus perfectly mixed with uniform colour. A degree of mixing of SA1 or SA2 can be interpreted as difficulties in enjoying normal meals.)

is difficult because, in the study by Takeshita et al., participants were grouped based on age rather than cognitive function, and the number of participants with mild cognitive impairment or mild dementia was not recorded [61]. Therefore, it should be investigated further whether independence in oral function should be given in participants with impaired cognition and, in particular, severe dementia. However, this was not the aim of the present study.

Furthermore, the discriminating power of the MMSE classification chosen in this analysis should be critically questioned. A different selection of cut-off values in the MMSE could possibly influence the outcome variables. An MMSE cut-off score of 23 is described as an ideal value to detect dementia with the MMSE instrument. However, the cut-off is dependent on the level of education [63, 64]. Additionally, the use of the MMSE in general must be questioned. For example, the MoCA test is known to meet the criteria for screening tests for mild cognitive impairment better than the MMSE [65]. Nevertheless, the authors decided to use the MMSE in the study because it is commonly used around the world, is time efficient, and was often available in the participants' medical records.

In the present analysis, only data from participants who were able to understand and independently carry out the tests were included in the analysis. Participants whose verbal or manual skills in dealing with the test procedures raised doubts about their ability to perform the tasks were excluded from the analysis ($n = 1$ in the

mDem group). This was the only way to ensure that the results were not influenced by inability to perform a test. The authors have deliberately refrained from using mean values for the analysis of data for both occlusal force and handgrip strength, despite the measurements being repeatedly performed for each variable. This was due to the fact that the investigator repeatedly noticed during the clinical trial that handgrip strength values were highest mainly during the first measurements. This could have been caused by rapid fatigue in the older participants. In contrast, the mean values of occlusal force were often highest only during the second measurement. This might be due to the fact that the participants had only “tried out” the test instrument the first time. Some participants expressed fears that this procedure may cause pain or damage to teeth and dentures. This study was not able to show a decline in maximum occlusal force as a function of the early stages of cognitive decline in an older population, as described in the literature [61]. A causal relationship between cognition and MOF (here, in community-dwelling older people [19, 61, 66]) and chewing efficiency, which has previously been shown in animal and human experimental studies [26], has been reported in the literature. This has not been confirmed in the present study. To our knowledge, this is the first study to assess an association between chewing efficiency and handgrip strength in a population with cognitive impairment or mild dementia. Therefore, the current findings cannot be directly compared to other studies.



The reason for this may be publication bias: studies with positive results may be more represented in the literature [67].

Handgrip strength measurements are dependent on age [68], sex, and ethnicity [69]. Age and gender-adapted norm values are additionally influenced by many factors such as height, weight, comorbidities, profession [70], and the nutritional status [71] of the participants. Therefore, values comparable to this study are hard to find in the literature because of different confounding variables in other studies. In this study, statistically significant differences in handgrip strength values as a function of the cognition of the participants have been observed. This corresponds to the literature. For example, Su et al. showed an association between a stronger handgrip strength and better performance in terms of cognitive function [72]. Conversely, Esteban-Cornejo

et al. observed an association between a lower handgrip strength and a higher risk of all-cause dementia incidence and mortality [73]. The clinical significance of these differences was also investigated by McGrath et al., who demonstrated that every 5 kg higher handgrip strength was associated with “0.97 lower odds for both future cognitive impairment and worse cognitive impairment” [74].

Statistically, the number of participants was considered high enough to be able to answer the authors’ question. A significantly higher number of cases can be assumed to have no further influence on the examined associations, since the medians of the examined parameters in the evaluation groups were close to each other.

The results of this study may have arisen due to various circumstances. It is therefore important to consider the possibility that a different statistical analysis or the use of cut-off values for handgrip strength adjusted for

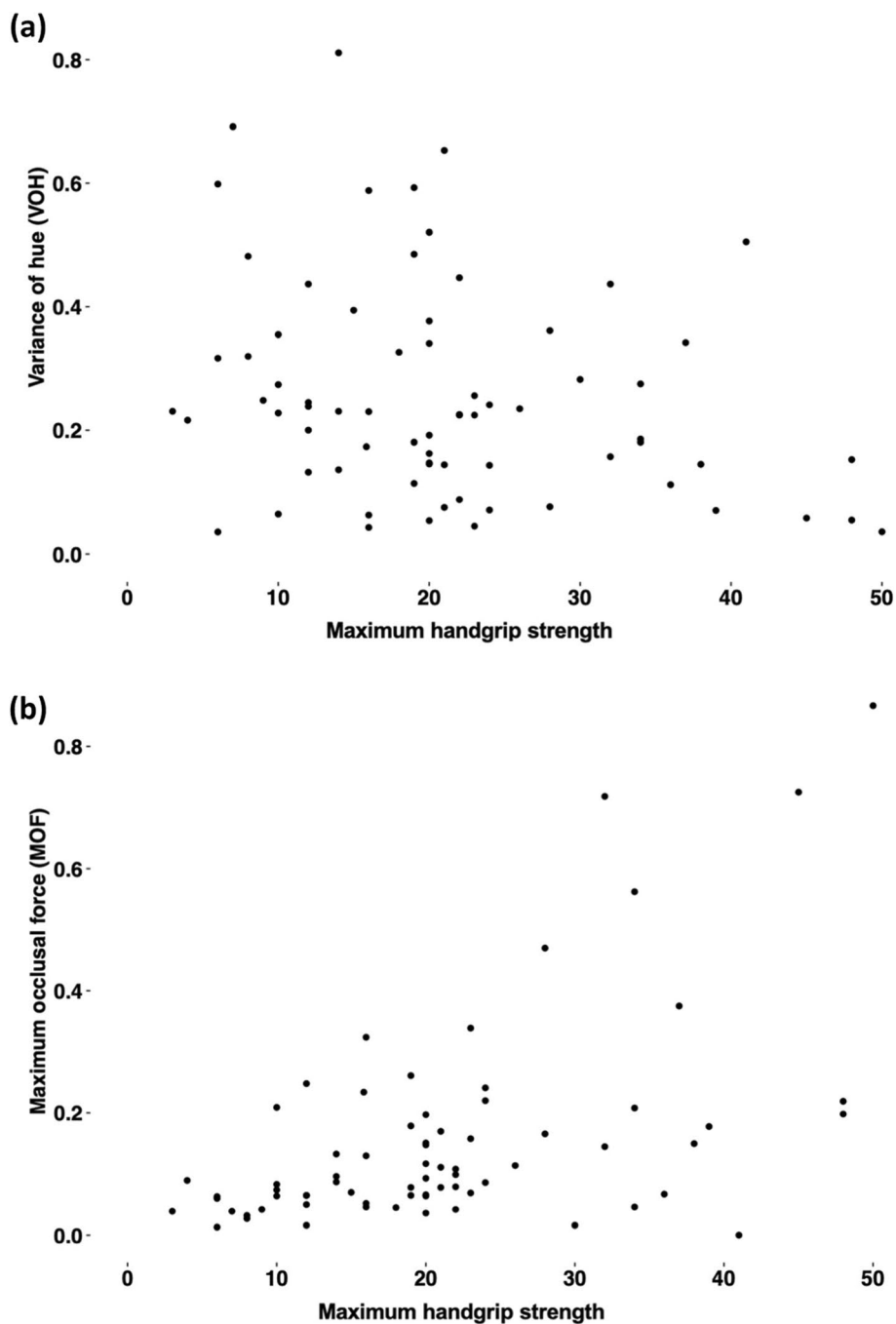


Fig. 4 Association between maximum handgrip strength and (a) Chewing efficiency (Variance of hue (VOH)) and (b) Maximum occlusal force (MOF)

gender and body mass index [75, 76] may have led to different results. As data may be analysed in different ways, it is important that the process is pre-specified in the study protocol. As a result, we followed our protocol and considered the correct approach from a scientific perspective.

In addition, study participants who were unable to perform the measurements due to cognitive impairment or dementia were excluded. The inclusion of a larger number of study participants with dementia who were able to perform the measurements might have been beneficial for the validity of the study.

Table 2 Association between maximum handgrip strength and the subjective assessment scale (SAS)

Subjective Assessment Scale (SAS)	Maximum handgrip strength [kg]		
	Mean \pm SD	Median	IQR
SA1	17.3 \pm 10.8	15	11.8
SA2	22.3 \pm 11.3	22	17.5
SA3	18.8 \pm 9.0	19	9.5
SA4	25.7 \pm 12.4	20	11.0
SA5	31.6 \pm 14.9	24	22.0

IQR Interquartile range, SAS Subjective assessment scale: SA1—chewing gum not mixed, impressions of cusps or folded once; SA2—large parts of chewing gum unmixed; SA3—bolus slightly mixed, but bits of unmixed original colour; SA4—bolus well mixed, but colour not uniform; SA5—bolus perfectly mixed with uniform colour

The authors assume that, since no association between handgrip strength and parameters of chewing function has been observed in this study, measurement of handgrip strength with the Jamar dynamometer does not appear to be a possible alternative to provide inferences about the chewing function of people with dementia.

Although various associations between chewing function and dementia have been described in the literature (e.g., [10, 25, 26, 28]), the method of carrying out the tests (e.g., mixing ability test [25]) and their reliability in people with dementia should be examined further. The main question arises as to how reliable the testing of chewing efficiency and MOF is in people with cognitive impairment and dementia. In the current study, only one test procedure each was used to evaluate MOF and chewing efficiency. Future studies should therefore investigate whether other test procedures for chewing efficiency (e.g., sieve method [3, 4], computer-aided particle analysis [5], degree of carrot comminution [6], chewing gum [77, 78], image analysis [79]) or for measuring bite force [80], with regard to performance, the compliance of the participants tested and reliability, are able to obtain more reliable results. Even the development of new diagnostic tests for chewing efficiency and occlusal force for people with dementia should be considered. Trautwein et al. conclude there is a “need for tailoring motor assessments” to people with cognitive impairment or dementia. In addition, the need for standardised assessment procedures has been emphasised [81].

An adaptation and analysis of the available test procedures is required in order to include people with cognitive impairment and dementia in research and to address age and cognitive impairment discrimination in studies. Additionally, feasible alternative measurements of muscle function, strength, and mass as alternatives for handgrip strength measurement that may be carried out by

people with cognitive impairment or dementia should be considered in further studies. The European Working Group on Sarcopenia in Older People has made suggestions regarding measuring methods used in research or clinical practice to evaluate the parameters of sarcopenia [82]. Concerning muscle mass measurements, computed tomography (CT), and magnetic resonance imaging (MRI) are described as the gold standard in the estimation of muscle mass but are mostly relevant for research purposes due to the radiation exposure patients are subjected to, as well as their high cost [82, 83]. An alternative is dual energy X-ray absorptiometry (DXA), which is used in clinical practice and research settings [83]. Bioimpedance analysis (BIA) may represent a well-studied [84], reproducible and easy-to-use portable alternative for DXA [82] in older subjects [85–87]. However, anthropometric measurements, which are easy to obtain in clinical practice, are not recommended for the diagnosis of sarcopenia [82]. Regarding muscle strength, there are fewer measuring methods available. Handgrip strength seems to be a simple and reliable method to measure muscle strength. Additionally, it is easier to carry out than measurement of the lower arm or leg strength [82]. Alternatives may include the measurement of peak expiratory flow or the measurement of knee flexion/extension, neither of which is recommended in clinical practice [82]. Since the main problem in this study concerned the measurement of chewing function or maximum occlusal force, the measurement of handgrip strength should be retained as an assessment method. Regarding physical function, the Short Physical Performance Battery (SPPB) can be used as a standard measure both in clinical practice and research [82, 88]. Next to the SPPB, the measurement of gait speed [88], and the timed get-up-and-go test may be helpful in clinical practice to define patients’ physical performance [82].

An ideal alternative for measuring hand force or even the parameters of a patient’s chewing point would need to meet various requirements. These include, among other things, the possibility of enabling the measurements in everyday life or their verification through observations or arbitrary reflexes. Furthermore, it would be purposeful if the measurements could be obtained without instructions, requirements, or complex devices and still be reliable and replicable at any time.

The authors assume that people with dementia could also benefit from an improvement in chewing function, as its associations with quality of life [9, 89], activities of daily living [9, 10], and nutritional status [89] are evident. Measurements of nutrition and quality of life should therefore be the subject of future clinical trials. This article provides an initial starting point to overcoming existing limitations in studies with people

with cognitive impairment and dementia by identifying future research questions. The use of sequential approaches in the development of test procedures, characterised by a gradual increase in complexity from simple to more difficult tasks, is recommended. Furthermore, tests used for motor skills assessment should have sufficient relative reliability for people with dementia. In their implementation, instructions should be adapted to the cognitive capacity of the participants. External guidance and assistance should also be allowed in test procedures [81].

Conclusions

The use of handgrip strength measurement as an alternative for determining the maximum occlusal force and chewing efficiency, tested with the GM 10[®] occlusal force meter and the colour-mixing ability test in people with cognitive impairment or dementia, has not been validated in this study. Further evaluations of chewing function are needed in terms of its feasibility and reliability in people with cognitive impairment and dementia. Adapting existing test procedures or developing new procedures that are easy to use for people with dementia may also be necessary.

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Authors' contributions

JJ was responsible for conceptualisation, methodology, investigation, data curation, writing—original draft preparation, visualisation, project administration, and funding acquisition. IN was responsible for conceptualisation, methodology, data curation, writing—review and editing, supervision, project administration, and funding acquisition. SH was responsible for data curation, writing—review and editing, and supervision. All authors have read and agreed to the published version of the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to the ethics approval guidelines but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Informed consent was obtained from all the participants involved in the study. All the participants or their legal representatives gave written informed consent.

The study was conducted in accordance with the Declaration of Helsinki and approved by the competent Cantonal Ethics Committee (CEC) of Zurich (KEK-ZH 2017–00363).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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