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The association of oral function with dietary intake and nutritional status among older adults: Latest evidence from epidemiological studies

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ABSTRACT

Inadequate and poor quality of diet and malnutrition are common and associated with adverse health outcomes, including morbidity and mortality, among older persons. This review aimed to establish the latest evidence from studies investigating the association between oral function and nutrition among older adults.

An electronic search of MEDLINE using PubMed for literature published in English between March 2018 and March 2021 was conducted, and 27 papers were identified. The selected studies comprised 23 observational studies (17 cross-sectional and 6 longitudinal studies) and 4 interventional studies. Most of the observational studies demonstrated the following associations in older adults: older adults with poor oral function are likely to have poorer dietary intake and poorer nutritional status, and malnourished older adults are likely to have poorer oral function. The results of the intervention studies demonstrated that the combination of prosthodontic treatment and dietary counseling is more effective for improving dietary intake and nutritional status in older persons with tooth loss than the prosthodontic treatment alone.

Our review confirmed that a relationship exists between oral function and nutrition and revealed the need for additional high-quality studies investigating comprehensive oral function, rather than a single aspect of oral function, with regard to nutritional status.

1. Introduction

Inadequate and poor quality of diet [1–3] and malnutrition (undernutrition) [4] are common among older people. An inadequate and poor-quality diet and malnutrition are associated with adverse events, including longer length of hospital stay, high medical care costs, morbidity, and death [5–9]. Considering its impact on individuals and society, poor nutrition is a serious health problem among older persons.

Poor oral functions such as decreased ability to chew and swallow lead to unfavorable changes in food choices and a poor quantity and quality of food intake among older adults [10–12]. Inadequate dietary intake is a risk factor for malnutrition [13]. Therefore, a scenario where oral disease leads to reduced oral function, which subsequently leads to lack of dietary intake and thus malnutrition, can be expected [14]. To date, several review articles have been published on the association between oral health and nutritional status [15–21]. However, most of the included papers investigated the dentition status or the presence of dental prostheses alone, and oral function has not been studied in detail in the context of nutritional status.

Recently, the concept of oral frailty has been introduced in Japan. According to the Japan Dental Association, oral frailty presents as a series of phenomena and processes characterized by vulnerable oral health status due to age-related changes in different oral health conditions (number of teeth, oral hygiene, oral functions, etc.), which is accompanied by a decreased interest in oral health and physical and mental reserve capacity, which can lead to deterioration in eating function, potentially resulting in physical and mental disorders [22]. Oral frailty is used to educate the public on the importance of oral function.

The importance of oral function is receiving more attention from clinicians, researchers, and citizens than ever before. There is a need to establish the latest evidence from studies investigating

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the association between oral function and nutrition among older adults. In this review, we examined papers that describe associations between oral functions and nutrition that were published in the past 3 years (between March 2018 and March 2021).

2. Methods

The MEDLINE database was searched using PubMed (http://www.ncbi.nlm.nih.gov/pubmed) for papers published in English between March 2018 and March 2021. The terms used for the PubMed search query were as follows:

(Öral Health[̈MH] OR M̈outh Diseases[̈MH] OR M̈astication[̈MH] OR D̈eglutition Disorders[̈MH] OR T̈ooth Diseases[̈MH] OR S̈aliva[̈MH] OR öral frailty[̈All Fields] OR öral pain[̈All Fields] OR m̈outh pain[̈All Fields] OR ẗongue pressure[̈All Fields] OR öcclusal force[̈All Fields] OR ẗongue-lip motor function[̈All Fields] OR f̈unctional dentition[̈All Fields]) AND (M̈alnutrition[̈MH] OR N̈utritional Status[̈MH] OR F̈ood[̈MH] OR D̈iet[̈MH] OR T̈hinness[̈MH] OR B̈ody Weight[̈MH] OR B̈ody Mass Index[̈MH]) AND Äged[̈MH] AND Ënglish[̈Language] AND 2018/03/15[PDAT]: 2021/03/15[PDAT].

The studies identified by the electronic search were screened by examining the titles and abstracts. Papers were determined to be eligible if they explored the association between both subjectively and objectively assessed oral function and nutritional status. Full texts of these eligible studies were further screened based on the following exclusion criteria: (1) case reports, in vitro studies, animal experiments, letters to the editor, systematic or narrative reviews, guidelines, or comments; (2) observational or interventional studies that did not include any of the following oral variables: tooth loss, use of dental prosthesis, any index of oral dryness, occlusal force, tongue-lip motor function, tongue pressure, masticatory performance, and swallowing function; (3) observational or interventional studies that did not use any objective index for nutritional status or quantitative data for dietary intake; and (4) observational or interventional studies that did not include individuals aged ≥65 years old.

Finally, the methodological and reporting quality was evaluated using the National Heart Lung and Blood Institute (NHLBI) quality assessment tool [23]. Studies were excluded if they met <50% of the NHLBI criteria. The NHLBI tool for observational studies comprises 14 items; of these, 10 are applicable to cross-sectional studies, and all 14 are applicable to longitudinal studies. The NHLBI tool for interventional studies comprises 14 items. The NHLBI tool is a widely used assessment tool for evaluating qualities of epidemiological studies. The NHLBI tool allowed for assessment of methodological flaws, such as sampling, adjustment for confounders, study power and other relevant factors for the study [23,24].

3. Results

3.1. Selected articles

A total of 453 articles were identified. Of these, 410 articles were excluded because the contents of the article, based on the title and abstract, did not meet our criteria. The full texts of 43 articles were reviewed in detail, and 9 articles (6 did not include appropriate oral variables, 2 did not include appropriate nutritional variables, and 1 did not include participants aged ≥65 years) were excluded based on the criteria listed in the Methods section. The final group of 34 articles underwent a methodological quality assessment. Seven studies with low methodological quality were excluded. Ultimately, 27 articles were included in this review (Fig. 1).

3.2. Study characteristics

The selected studies included 23 observational studies [25–46] (17 cross-sectional [25–31,33–35,37,38,40,42,43,45,46] and 6 longitudinal designs [28,30,32,36,39,44]) and 4 interventional studies [47–50]. The number of study participants ranged between 32 and 28,738.

Various nutritional variables were used in the studies. These variables can be categorized as nutritional assessment or screening tools (listed in Table 1), measures of anthropometry including body composition (e.g., body mass index [BMI], muscle mass, and body fat), biochemical markers (e.g., serum albumin level), and diet quality and quantity. Different studies also had different definitions of oral function, which included dentition status, objectively and subjectively assessed oral functions such as masticatory and swallowing abilities, dysphagia assessment or screening tools (MD Anderson Dysphagia Inventory [MDADI], 10-item Eating Assessment Tool [EAT-10], and Functional Oral Intake Scale), and oral frailty defined as a multicomponent phenotype of poor oral function. Dentition status is a morphological aspect of oral health; however, this index is included in the component of oral frailty [51]. Therefore, we decided to include this index in our review.

3.3. Observational cross-sectional studies investigating the association of oral functions with nutrition

Among the 17 observational cross-sectional studies [25–27,29,31,33–35,37,38,40–43,45,46,52] included in this review, 16 studies [26–29,31–38,40–46,52] revealed an association between oral function and nutrition. One study [25] found no association. The author, publication year, setting, participants, measures (exposure and outcome), and results are summarized in Table 2. We presented key results of each study in a numerical form that includes estimates of associations and appropriate measures of variability and uncertainty (e.g., regression coefficients or odds ratios with confidence intervals).

Nine studies [26,29,33,35,38,40,42,45,46] included community-dwelling older adults. Bassim et al. [42] explored the cross-sectional associations among poor oral health, poor diet, and frailty in Canadian adults aged 45–85 years. This is the largest study included in this review. Oral functions were assessed using a self-administered questionnaire that included questions about oral health problems (dry mouth, chewing inadequacy, etc.). Based on the responses to these questions, a cumulative oral health deficit score (ranging from 0 to 24) was calculated and used to operationalize poor oral health. Dietary intake of seven food groups that are considered healthy—fruits, vegetables, nuts, legumes, fish, dairy, and meats (chicken and red meats)—was estimated by using a questionnaire. Based on the consumption level of each food group category, the overall diet score, ranging from 0 to 28, with a higher score indicating lower consumption of healthy food groups or a worse diet, was generated. Frailty was operationalized by calculating a frailty index that was created based on Rockwood's frailty index [53]. Interrelationships among oral health deficit score, overall diet score, and frailty index were studied using path analysis. As a result, poorer oral health (higher oral health deficit score) was associated with a higher score on the poor diet scale. Moreover, path analysis revealed that poorer oral health indirectly affects frailty status through a poor score on the diet scale. This study is important because the study findings support long-discussed pathways linking poor oral health and frailty through diet. It should be noted, however, that the indirect effect of poor oral health through a poor diet was modest (i.e., representing only approximately 1% of the direct effect of poor oral health on frailty). Similar results were found among the National Health and Nutrition Examination Survey (NHANES) participants aged ≥60 years. Hakeem et al.

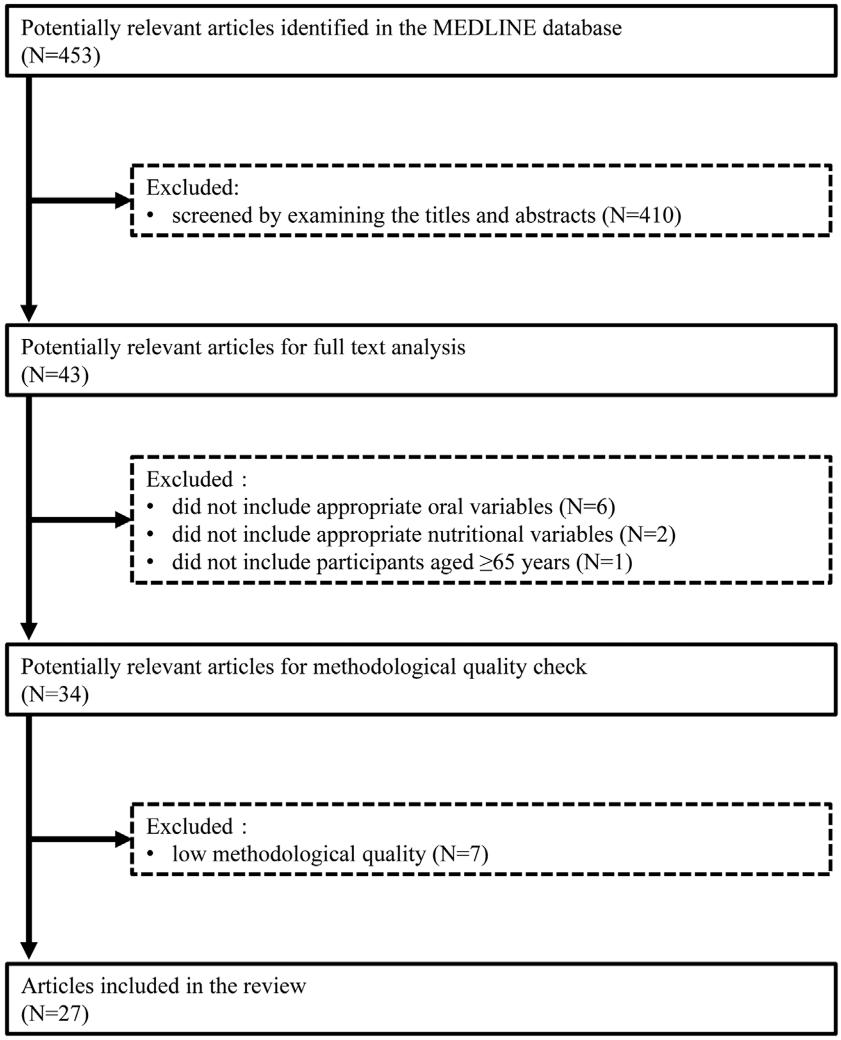

Fig. 1. Flowchart of the study selection.

Table 1
Nutritional assessment or screening tools used in the studies included in our review.

Nutritional assessment or screening tools	Score interpretation	[#Ref.]
Mini Nutritional Assessment	The lower the score, the greater the risk for malnutrition	[25,29,31,35,37,38,43,44]
Geriatric nutritional risk index	The lower the score, the greater the risk for malnutrition	[34]
Patient-Generated Subjective Global Assessment	The higher the score, the greater the risk for malnutrition	[36]
Prognostic nutritional index	The lower the score, the greater the risk for malnutrition	[52]
Minimal Eating Observation and Nutrition Form version II	The higher the score, the greater the risk for malnutrition	[27]
Malnutrition Universal Screening Tool	The higher the score, the greater the risk for malnutrition	[41]

[#Ref.] indicates the reference number for the studies using the tools.

[54] found that the number of teeth was negatively associated with frailty and that nutritional intake had a modest effect on this relationship among NHANES participants. The findings of Bassim's study also indicate that oral functions were associated with diet and frailty in a dose-response manner. The cumulative effects of poor oral functions were operationalized as oral frailty [51]. We also obtained results consistent with Bassim's study. We observed that oral frailty was associated with the presence and severity of malnutrition among community-dwelling older Japanese individuals [29]. The strength of our study was that unlike Bassim's study, we used clinical data to assess oral function and defined nutritional status by using the Mini Nutritional Assessment-short form (MNA-SF), a validated and widely used nutrition screening tool, and serum albumin level.

Other studies of community-dwelling older adults revealed associations between oral stereognostic ability and dietary intake [26], between masticatory function assessed using color-changeable chewing gum and serum albumin level [45], between self-rated masticatory function and dietary intake [46], and between occlusal force and serum albumin level [33]. Unlike other studies conducted in a community setting that used oral function as an exposure, the study of Tagliaferri et al. [35] used low swallowing ability as an outcome. They reported that a higher MNA-SF score was associated with lower odds of swallowing difficulties, defined as an EAT-10 score ≥3.

The associations of oral aspects and function with nutritional status were also studied in older adults at a hospital, nursing home, and other health care facilities. Six studies [25,27,37,41,43,52] used

Table 2
Overview of included observational cross-sectional studies investigating the association of oral function with dietary intake and nutritional status.

Author [#Ref.]	Year	Setting	Participants	Measures			Results
			n	Age	Exposure	Outcome	
Abe et al. [52]	2019	Hospital	93	Mean (s.d.) = 69.0 (9.2), 72.9 (8.8), and 73.5 (9.7) for the group with Eichner index A, B, and C	Eichner index	PNI	Compared with gastric cancer patients with Eichner index A, those with Eichner index C had a lower PNI (coefficient = −3.93, $p < 0.01$).
Bassim et al. [42]	2020	Community	28,738	Range = 45–85	Number of self-reported oral health problems (e.g., dry mouth, chewing inadequacy)	Poor diet scale	Poorer oral health was associated with increased poor diet scale scores (linear regression model, standardized beta [95% CI] = 0.40 [0.20–0.61] for those with 1 oral health problem and 0.76 [0.57–0.95] for those with ≥2 oral health problems).
Blanař et al. [41]	2019	Hospital/nursing home	17,580	Mean (s.d.) = 68.5 (18.8) for the group with MUST of ≥1 and 67.1 (17.5) for the group with MUST of 0	Self-reported swallowing problems	Malnutrition (defined as MUST of ≥1)	Patients with self-reported swallowing problems had higher odds of malnutrition (logistic regression model, adjusted OR [95% CI] = 2.2 [1.9–2.5]).
Chatindiara et al. [43]	2018	Hospital	234	Mean (s.d.) = 83.6 (7.6)	EAT-10	MNA-SF	High EAT-10 score was associated with low MNA-SF score (Poisson regression model, adjusted PR [95% CI] = 0.98 [0.97–0.99]).
de Medeiros et al. [25]	2020	Nursing home	344	Mean (s.d.) = 77.7 (9.1)	Masticatory performance (variance of hue) Swallowing threshold (number of chewing cycles)	MNA-SF score, BMI, muscle mass (kg), and body fat (%)	The masticatory performance and swallowing threshold were not correlated with MNA-SF total score (r = −0.058, p = 0.30 for masticatory performance and r = 0.073, p = 0.20 for swallowing threshold), BMI (r = −0.015, p = 0.83 for masticatory performance and r = 0.053, p = 0.45 for swallowing threshold), muscle mass (r = 0.003, p = 0.96 for masticatory performance and r = −0.012, p = 0.86 for swallowing threshold) or body fat (r = −0.078, p = 0.26 for masticatory performance and r = 0.115, p = 0.10 for swallowing threshold).
Fukutake et al. [26]	2018	Community	164	≥69	OSA	Dietary intake assessed using BDHQ	OSA score was associated with intake of green and yellow vegetables (linear regression model, β = 0.16, p = 0.03) and α-tocopherol (β = 0.16, p = 0.03).
Gaewkhiew et al. [40]	2019	Community	788	≥60	Presence of FD and dentures	Underweight (BMI < 18.5 kg/m^2), overweight or obese (BMI > 25 kg/m^2), and nutrient intake estimated using FFQ	Study participants with FD were less likely to be underweight than those with neither FD nor dentures (Poisson regression model, adjusted PR [95% CI] = 0.39 [0.16–0.95]).
Hägglund et al. [27]	2019	Institutionalized	391	Median (IQR) = 84 (78–89)	Swallowing dysfunction defined by a timed water swallow test	Malnutrition (MEONF-II ≥3)	Study participants with swallowing dysfunction had higher odds of malnutrition (logistic regression model, adjusted OR [95% CI] = 1.74 [1.04–2.92]).

Table 2 (*Continued*)

Author [#Ref.]	Year	Setting	Participants	Measures			Results
			n	Age	Exposure	Outcome	
Iwasaki et al. [29]	2020	Community	1054	Mean (s.d.) = 77.0 (4.8)	Oral frailty	Malnutrition (MNA-SF categorization and serum albumin)	Study participants with oral frailty had higher odds of malnutrition (logistic regression model, adjusted OR [95% CI] = 2.17 [1.58–2.98] for MNA-SF categorization and 1.59 [1.10–2.31] for serum albumin).
Izumi et al. [37]	2020	Hospital	52	≥65	Tongue pressure	Malnutrition (MNA-SF <12)	Greater tongue pressure was associated with lower odds of malnutrition (logistic regression model, adjusted OR [95% CI] = 0.88 [0.88–0.99].
Lindroos et al. [31]	2019	Nursing home	3123	Mean (s.d.) = 84 (8), 85 (7), 85 (8), and 84 (8) in group with 0, 1, 2, and 3 oral health symptoms.	MNA	Chewing problems, swallowing difficulties, and dry mouth assessed by trained nurse (no specific tests were used)	Malnutrition evaluated using MNA classification was associated with several oral symptoms (logistic regression model, adjusted OR [95% CI] = 0.50 [0.41–0.59] for being at risk of malnutrition and 0.27 [0.20–0.36] for being well-nourished compared with the malnourished population).
Motokawa et al. [45]	2021	Community	509	≥65	Chewing ability assessed using color-changeable chewing gum	Malnutrition (serum albumin <4.0 g/dL)	Study participants with low chewing ability had higher odds of malnutrition (logistic regression model, adjusted OR [95% CI] = 1.5 [1.004–2.0]).
Natapov et al. [46]	2018	Community	1776	≥65	Self-reported chewing problems	Dietary intake estimated by 24 h dietary recall method	Dietary intakes of energy (1355 kcal [with chewing problems] vs. 1480 kcal [without chewing problems]), dietary fiber (15.3 g vs. 17.6 g), protein (3.2 servings vs. 3.5 servings), and vegetables (2.0 servings vs. 2.4 servings) were lower in study participants with chewing problems than in those without (linear regression model).
Nishida et al. [38]	2021	Community	320	≥65	Dysphagia defined as EAT-10 of ≥3	Malnutrition (MNA-SF<12) and prefrailty or frailty assessed using CHS criteria	Dysphagia was associated with malnutrition (logistic regression model, adjusted OR [95% CI] = 4.0 [1.9–8.2]) and frailty status (logistic regression model, adjusted OR [95% CI] = 2.3 [1.0–5.2]).
Okamoto et al. [33]	2019	Community	3134	Median (IQR) = 71 (68–75)	Number of teeth and occlusal force	Low serum albumin (<4.4 g/dL) and low BMI (<21.0 kg/m^2)	Compared with the women with an occlusal force of ≥500 N, those with an occlusal force of <300 N had higher odds of low serum albumin (logistic regression model, adjusted OR [95% CI] = 1.65 [1.06–2.55] for the group with 100–300 N and 1.95 [1.15–3.31] for the group with <100 N).
Saito et al. [34]	2018	Hospital	165	Median = 76	Malnutrition defined as GNRI of <91.2	Dysphagia defined as PAS of 4–8	Compared with the patients without malnutrition, those with malnutrition had higher odds of dysphagia (logistic regression model, adjusted OR [95% CI] = 3.1 [1.1–9.1]).
Tagliaferri et al. [35]	2019	Community (outpa-tients)	773	Mean (s.d.) = 82.0 (7.1)	MNA-SF	Swallowing difficulties defined as EAT-10 of ≥3.	Higher MNA-SF score was associated with lower odds of swallowing difficulties (logistic regression model, adjusted OR [95% CI] = 0.91 [0.83–0.99]).

β = standardized coefficient, BMI = body mass index, CHS = Cardiovascular Health Study, CI = confidence interval, EAT-10 = 10-item Eating Assessment Tool, FD = functional dentition, FFQ = food frequency questionnaire, GNRI = geriatric nutritional risk index, IQR = interquartile range, MEONF-II = Minimal Eating Observation and Nutrition Form version II, MUST = Malnutrition Universal Screening Tool, OR = odds ratio, OSA = oral stereognostic ability, PAS = penetration–aspiration scale, PNI = prognostic nutritional index, PR = prevalence ratio, r = correlation coefficient, s.d. = standard deviation.

oral function as an exposure. Among them, 3 studies found that low swallowing ability was associated with malnutrition assessed using the Malnutrition Universal Screening Tool [41], MNA-SF [43], or Minimal Eating Observation and Nutrition Form version II [27]. Abe et al. [52] found that study participants without functional dentition were likely to have poor nutritional status. Izumi et al. [37] found that greater tongue pressure was associated with a lower prevalence of malnutrition as defined by MNA-SF. One study [25] reported that masticatory performance that was assessed based on the degree of color mixing of a two-color chewing gum was not associated with MNA-SF or body composition.

On the other hand, 2 studies [31,34] used low swallowing ability as an outcome. These studies found that study participants with poor nutritional status tended to have poor oral functions.

3.4. Observational longitudinal studies investigating the association of oral functions with nutrition

Among the 6 longitudinal studies [28,30,32,36,39,44] included in this review, 4 studies [28,32,36,44] found an association between oral function and nutrition. Two studies [30,39] found no association. The author, publication year, setting, participants, measures (exposure and outcome), and results are summarized in Table 3.

Hiratsuka et al. [28] found that a lower number of teeth was associated with increased mortality mediated by low serum albumin levels. Logan et al. [32] found that having 21 or more natural teeth remaining was positively associated with dietary intake of fruit, vegetables, and nuts and resulted in higher diet quality scores compared with those of individuals with severe tooth loss. Wang et al. [36] collected clinical data from 122 patients with head and neck cancer undergoing radiotherapy (RT) at three time points: baseline, the third week of RT, and upon completion of RT. They found that the swallowing functional outcomes assessed using the MDADI worsened over the course of RT and were associated with a lower weight ratio (present weight/baseline weight $\times$ 100%) and worsened nutritional status assessed using the Patient-Generated Subjective Global Assessment. Maeda et al. [44] found that malnutrition at the time of admission was associated with a higher risk of swallowing disorder development at discharge among older adults. The link between malnutrition and swallowing disorders is thought to be that sarcopenic changes in eating-related muscles occur due to poor nutritional status [55]. It should be noted, however, that no definitive conclusion can be drawn because this interpretation is based on a single cross-sectional observational study [44]. It may be more biologically plausible that older people with swallowing disorders have problems getting an adequate diet and so end up poorly nourished.

3.5. Intervention studies investigating the effect of prosthetic intervention on nutritional status

Four interventional studies (3 randomized controlled trials [RCTs] [47–49] and one non-RCT [50]) were identified (Table 4). These studies investigated the combined effect of dental prosthesis treatments, including complete or partial denture fabrication, and dietary advice or counseling on nutritional status among older adults. Of note, none of the included studies investigated the effect of dental prosthesis treatment alone. There is evidence that dietary advice or counseling may improve nutritional status in older people affected by undernutrition [56–58]. The three RCTs investigated complete denture (CD) fabrication and simple dietary advice provided by dentists using a pamphlet prepared with reference to the geriatric version of the Japanese Food Guide Spinning Top published by the Japanese Ministry of Agriculture, Forestry and Fisheries [59]. Compared to the control group (i.e., without dietary advice), the intervention group (i.e., with dietary advice) showed higher dietary intakes of several nutrients, including protein [48], at the 3-month posttreatment examinations and showed higher nutrient intake [47] and a higher MNA-SF score [49] at the 6-month posttreatment examinations. On the other hand, Nabeshima et al. [50] examined the effect of dietary counseling by nutritionists on dietary intake among older patients who received partial denture (PD) placements (before-after design with no control group). They observed that dietary intake of vegetables, α- and β-carotenes, and dietary fiber was higher at a follow-up evaluation 3 months after PD placement.

4. Discussion

Multiple studies published in the past 3 years have demonstrated the association between oral function and nutrition in older adults. Of note, two longitudinal studies [28,32] indicated that poor oral function increased the risk of malnutrition in community-dwelling older adults. One longitudinal study [36] also demonstrated temporal associations of poor oral function with malnutrition in hospitalized older adults. Furthermore, in the hospital setting, another longitudinal study [44] demonstrated an association between oral function and nutritional status in the opposite direction; that is, malnutrition led to poor oral function.

The prevalence of oral diseases increases with advancing age [60]. Oral diseases can cause poor oral function, including masticatory and swallowing hypofunction, which may result in a deterioration of nutritional intake, ultimately leading to malnutrition. On the other hand, malnutrition adversely affects muscle mass and strength [61]. This notion can also apply to eating-related muscles [44] and ultimately leads to a decline in oral function. Because more studies investigating the effects of malnutrition on oral function were conducted in inpatient study populations [31,34,44] than in outpatient populations [35], the adverse effects of malnutrition on muscle functions may be pronounced in frail persons. A recent intervention study revealed that a high-calorie diet provided energy for patients with dysphagia and improved their swallowing ability [62].

There is another potential pathway through which malnutrition might be connected to poor oral function. Malnutrition has adverse effects on the host defense system [63] and thus can increase the risk for oral diseases. In addition, several nutrients, such as carotenoids and vitamins C and E, have anti-inflammatory and antioxidant properties [64]. Inadequate intake of these nutrients due to poor oral function may increase the risk of periodontitis [65,66]. Overall, a negative cycle where poor oral function leads to malnutrition, which leads to oral diseases, which lead to poor oral function can be expected. Maintaining good oral function at an advanced age is thus important for preventing individuals from falling into such a negative cycle.

Swallowing function was the most used indicator for oral function across the studies included in this review. In a previous systematic review on the association between oral health and malnutrition in older adults in a long-term care facility, masticatory function was the most used indicator [15]. Another systematic review examined mastication function [19]. Recently, swallowing function has attracted increasing attention with regard to nutritional status.

Because individual oral health problems are interrelated and their prevalence increases with age, older adults frequently have coexisting oral health problems [29,67]. Oral frailty has been introduced as a state of deterioration of multiple oral functions [51]. Further studies investigating the association between comprehensive oral function and nutrition are warranted.

Table 3
Overview of included observational longitudinal studies investigating the association of oral function with dietary intake and nutritional status.

Author [#Ref.]	Year	Setting	Participants		Measures		Results
			n	Age	Exposure	Outcome	
Gaewkhiew et al. [39]	2020	Community	651	≥60	Presence of FD and dentures	BMI, WC, TSF, and nutrient intake estimated using FFQ	Presence of FD and dentures at baseline was not associated with 12-month changes in BMI, WC, TSF, and nutrient intake.
Hiratsuka et al. [28]	2020	Community	891	Mean (s.d.) = 75.5 (4.7)	Number of teeth	All-cause mortality Mediator = malnutrition (serum albumin <3.8 g/dL)	Having 1−9 teeth was associated with increased mortality mediated by malnutrition compared with having ≥20 teeth (mediation analysis, mediation proportion [95% CI] = 10.0 [3.0–28.7]).
Kiesswettera et al. [30]	2019	Community	893	Mean (s.d.) = 67.6 (6.1)	Oral health characteristics based on self-report	Self-reported involuntary weight loss of ≥5% or low BMI (<20 kg/m^2 and <22 kg/m^2 in participants <70 and ≥70 years, respectively)	Toothache while chewing was associated with incidence of malnutrition (Cox-proportional hazard regression model, adjusted HR [95% CI] = 2.14 [1.10–4.19]). Self-rated oral health status (2.10 [0.88–4.98]) and xerostomia with edentulous (1.99 [0.93–4.28]) were close to the level of significance.
Logan et al. [32]	2020	Community	1096	Mean (s.d.) = 67.6 (6.1)	Dentition status: 21–28 teeth with and without dentures, 1–20 teeth with and without dentures, and edentate with dentures	Dietary intake estimated using FFQ	After an average time period of 13 years, having 21 or more natural teeth remaining was positively associated with dietary intake of fruit, vegetables, and nuts and resulted in higher diet quality scores (MDS and DDS) compared with those with severe tooth loss (i.e., 1–20 teeth or edentate) (linear regression model).
Maeda et al. [44]	2019	Hospital	8768	Mean (s.d.) = 76.1 (6.9)	BMI, MNA-SF, and amount of food intake at admission	Decline in swallowing ability indicated by FOIS of ≤5 at discharge	Malnutrition evaluated using MNA-SF (logistic regression model, adjusted OR [95% CI] = 0.92 [0.87–0.97]) and insufficient nutritional intake (OR [95% CI] = 2.33 [1.60–3.40]) were associated with swallowing disorder development.
Wang et al. [36]	2020	Hospital (patients with head and neck cancer undergoing RT)	122	Mean (s.d.) = 51.3 (15.2)	MDADI	Weight ratio (present weight/baseline weight × 100%) and PG-SGA	Poor swallowing functional outcomes related to a lower weight ratio (GEE, regression weight = 0.032, p = 0.01) and worsened nutritional status (regression weight = −0.115, p < 0.01).

β = standardized coefficient, BMI = body mass index, CI = confidence interval, DDS = dietary diversity score, FD = functional dentition, FFQ = food frequency questionnaire, FOIS = functional oral intake scale, GEE = generalized estimating equation, HR = hazard ratio, IQR = interquartile range, MDADI = MD Anderson Dysphagia Inventory, MDS = Mediterranean diet score, OR = odds ratio, PG-SGA = Patient-Generated Subjective Global Assessment, RT = radiotherapy, s.d. = standard deviation, TSF = triceps skinfold thickness, WC = waist circumference.

Table 4
Overview of included intervention studies investigating the effect of prosthetic intervention on dietary intake and nutritional status.

Author [#Ref.]	Year	Participants		Design RCT/non-RCT	Study period	Measures		Results
		n	Age			Intervention	Outcome	
Kanazawa et al. [47]	2019	70 (intervention: n = 35, control: n = 35)	Mean (s.d.) = 74.8 (8.0) in the intervention group and 78.6 (6.8) in the control group	RCT	6 months	Intervention group: maxillary and mandibular CD fabrication and dietary advice Control group: maxillary and mandibular CD fabrication	Dietary intake estimated by BDHQ	Higher dietary intakes of several nutrients including protein (ANCOVA, mean = 100.2 g in intervention group vs. 93.3 g in control group, $p < 0.01$) were seen in the intervention group at 3 months post-intervention, but not at 6 months post-intervention.
Nabeshima et al. [50]	2018	32	Mean (s.d.) = 73.2 (7.7)	Non-RCT	3 months	PD placement and dietary counseling	Dietary intake estimated by BDHQ Serum concentration of carotenoids and vitamin C	Dietary intake of vegetables (linear mixed model, effect size between post-intervention and baseline = 74 g), α- (70 μg) and β-carotenes (1036 μg), and dietary fiber (2.5 g) increased at follow-up evaluation 3 months after the PD placement. Serum concentration of carotenoids and vitamin C remained consistent.
Suzuki et al. [48]	2018	62 (intervention: n = 31, control: n = 35)	Mean (s.d.) = 75.3 (8.2) in intervention group and 78.6 (6.6) in control group	RCT	3 months	Intervention group: maxillary and mandibular CD fabrication and dietary advice Control group: maxillary and mandibular CD fabrication	Dietary intake estimated by BDHQ	Higher dietary intakes of several nutrients, including protein (ANCOVA, mean = 101.6 g in intervention group vs. 93.5 g in control group, $p < 0.01$), were seen in the intervention group at 3 months postintervention.
Suzuki et al. [49]	2019	59 (intervention: n = 30, control: n = 29)	Mean (s.d.) = 74.8 (8.0) in intervention group and 78.6 (6.8) in control group	RCT	6 months	Intervention group: CD fabrication and dietary advice Control group: CD fabrication	MNA-SF	Higher MNA-SF score (Mann–Whitney U test, median [IQR] = 13 [13,14] in intervention group vs. 13 [11–13] in control group, $p < 0.01$) was seen in the intervention group at 6 months postintervention.

ANCOVA = one-way analysis of covariance, BDHQ = brief-type self-administered diet history questionnaire, CD = complete denture, PD = partial denture.

It should be noted that most of the studies included in this review investigated a single aspect of oral function with regard to nutrition. The results of intervention studies included in this review demonstrate the importance of dietary intervention during prosthetic treatment. These results are in agreement with those of earlier studies [68,69]. Moreover, previous RCTs did not produce consistent results supporting the effects of prosthetic treatment alone on older patients' nutritional status [70,71]. Dietary advice or counseling is effective by itself to improve nutritional status in older people [56–58]. Overall, available evidence indicates the importance of multidisciplinary cooperation involving professionals in dentistry and nutrition to improve the nutritional status of older persons with tooth loss.

This review has some limitations. We searched a single electronic database. In addition, we did not search non-English language publications or unpublished studies. This limited search strategy may have led to some relevant studies being missed.

5. Conclusions

The current review revealed that research findings support a potential relationship of poor oral function with an inadequate and poor-quality diet and malnutrition. Older adults with poor oral function are likely to have poorer dietary intake and poorer nutritional status, and malnourished older adults are likely to have poorer oral function. Maintaining good oral function may be a key for longevity. However, currently, there is limited evidence from longitudinal studies, and comprehensive oral function is not studied in detail, indicating the need for additional high-quality studies.

Furthermore, the combined effects of dental and dietary interventions should be examined in more detail by conducting interventional studies. These studies should explore (1) the durations for which the intervention effects last and (2) whether the degree of the effects of dietary interventions differ based on the provider (i.e., professionals in nutrition or nonprofessionals) and the frequency and timing of the intervention. Moreover, well-designed studies that compare the nutritional outcomes between two groups with the same nutritional interventions but delayed or immediate dental interventions are necessary to better evaluate the combined effects of dental and dietary interventions. Such studies are important for gaining insight into a more effective interprofessional approach for nutritional management in older adults in dental clinical settings.

Conflict of interest

None.

Role of the funding source

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Data availability

The data supporting this review were obtained from previously reported studies and datasets, which have been cited.

Ethics approval

No ethical approval was needed because data from previously published studies in which informed consent was obtained by primary investigators were retrieved and analyzed.

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