Deterioration of Oral Functions and Nutrition in Older Individuals

Kiyomi Iyota1 · Shinsuke Mizutani1,2

Accepted: 18 April 2022 /Published online: 2 May 2022 © The Author(s) 2022

Abstract

Purpose of Review Oral functions, which are responsible for feeding and swallowing, play a very important role in obtaining proper nutrition. Therefore, their deterioration could interfere with nutritional ingestion. This review investigated previous reports on the relationship between oral function deterioration and malnutrition.

Recent Findings Reduced occlusal force, decreased tongue–lip motor function, decreased tongue pressure, decreased masticatory function, and deterioration of swallowing function have been found to be associated with malnutrition. On the other hand, consensus does not exist on whether oral dryness is associated with malnutrition. Prosthetic rehabilitation and oral function training are effective interventions for improving oral functions. However, malnutrition could not be addressed by prosthetic rehabilitation alone; it requires simultaneous management with prosthetic rehabilitation and nutritional guidance. Furthermore, it has been reported that data on whether oral function training, such as tongue strengthening training, could improve malnutrition are limited.

Summary Partial deterioration of oral functions can cause malnutrition. Prosthetic rehabilitation and oral function training could be considered interventions for improving malnutrition, but numerous unclarified points about these methods remain. In the future, detailed research should be conducted to elucidate the causal relationship between deterioration of oral functions and malnutrition and to establish oral function interventions for improving malnutrition.

Keywords Oral hypofunction · Mastication · Malnutrition · Dysphagia · Mouth rehabilitation

Introduction

Oral functions, which are responsible for feeding and swallowing, play a significant role in obtaining proper nutrition. Problems with feeding and swallowing may render the intake of enough foods to meet the required nutritional amount impossible. In addition, teeth are very important for chewing. The fewer teeth there are, the more unchewable foods become. Also, even if a sufficient number of teeth remain, foods cannot be sufficiently chewed if dental caries or periodontal disease is present. On the other hand, even if the number of remaining teeth is small, appropriate treatment at a dental clinic is viable, with prosthetic treatment able to allow for the amount of food that can be chewed to increase. However, for feeding and swallowing, not only the teeth but also other oral parts, such as the tongue and saliva, play a very significant role. Saliva processes food particles that have been reduced in size by being chewed to the optimum viscosity for swallowing, and the movement of the tongue is involved in the formation of bolus and its transport to the oropharynx. Therefore, deterioration of oral function might cause nutritional status deterioration. Aging is considered to be the primary risk factor for deterioration of oral function, but secondary risk factors that occur with aging have also been identified, such as decreased physical and social activities [1], malnutrition [2], cognitive decline [3], decrease in the number of remaining teeth [4], and systemic diseases [5].

The concepts of oral frailty and oral hypofunction have become widespread in Japan. Oral frailty is the term that...
indicated a slight decline in oral functions, such as slight choking/spilling at eating when swallowing and decreased articulation, for which a clear set of evaluation criteria has not yet been established. On the other hand, oral hypofunction is a diagnostic condition proposed by the Japanese Society of Gerodontology in 2016; unlike conventional organic disorders, it is a pathological condition that results from a combination of several factors caused by oral function deterioration. It is characterized by the presentation of the following seven conditions: poor oral hygiene, oral dryness, reduced occlusal force, decreased tongue–lip motor function, decreased tongue pressure, decreased masticatory function, and deterioration of swallowing function. It is diagnosed if the criteria for at least three of these conditions are met [6]. This review provides a comprehensive report on the relationship between malnutrition and each condition of oral hypofunction, adding up-to-date evidence to previous reviews.

**Decreased Masticatory Function and Nutrition**

Decreased masticatory function results from malnutrition and decreased metabolic rate caused by spilling food, choking when swallowing, and an increase in the number of unchewable foods [6]. By measuring the glucose concentration obtained from chewed gummy jelly, two cross-sectional studies found that masticatory function is related to nutritional ingestion. In a study conducted on middle-aged individuals, Bori et al. reported that the intake of some nutrients (minerals, calcium, vitamin D, and vitamin B2) and foods (small fish with bones and non-oily fish) in the low-masticatory-function group was significantly lower than that in the healthy group (P < 0.05) [7•]. Furthermore, in a study conducted on individuals aged 90 years, Karawekpanyawong et al. reported that those with lower masticatory function had a lower intake of folic acid (r = -41.449; 95% confidence interval [CI] = -73.231 to -9.667) and vitamin A (r = -199.522; 95% CI = -365.524 to -33.520) compared with those with higher masticatory function [8•]. However, few intervention reports showing that the masticatory function itself is improved or that the improvement of the masticatory function leads to an improvement of malnutrition have been published in the literature. The scarcity of available data can be attributed to the fact that the masticatory function is a complicated function in which various factors, such as occlusion, tongue–lip motor function and muscle strength, and saliva secretion, are intertwined.

**Reduced Occlusal Force and Nutrition**

Several studies have reported an association between reduced occlusal force and nutritional ingestion. In a study conducted on 1004 individuals aged ≥40 years who were living in a provincial city, Nishi et al. reported that occlusal force was significantly and independently associated with protein ingestion (odds ratio [OR] = 0.98; 95% CI = 0.96–1.00) [9•]. Also, occlusal force has been reported to be influenced by the number of remaining teeth [6], with a decrease in the number of remaining teeth causing a change in nutritional ingestion and food intake. In a 5-year cohort study, Wakai et al. found that as the number of remaining teeth decreased, the average intake of some nutrients (carotene, vitamin A, and vitamin C) and food groups (milk and dairy products and vegetables, including green and yellow vegetables) decreased (P for trend, <0.05), whereas the average intake of carbohydrates and food groups (rice and confectionery) increased (P for trend, <0.05) [10]. Moreover, in a study conducted on 8815 Japanese individuals, Nakamura et al. reported that the intake of grain products and that of vegetables and meat were higher and lower, respectively, in individuals with fewer teeth compared with individuals with more teeth [11]. They also found that the intake of carbohydrates and that of multiple nutrients (protein; potassium; zinc; vitamins A, E, and B6; β-carotene; and folic acid) were higher and lower, respectively, among individuals with fewer teeth (P for trend, <0.01) [11].

Research has demonstrated that a reduction in the number of remaining teeth leads to not only reduced occlusal force but also decreased masticatory function. Especially, the number of functional tooth units (FTUs), which is the number of teeth in the pair of teeth opposite the maxilla and mandible—excluding the third molar, is significant. In a systematic review that analyzed 18 studies, Naka et al. concluded that the masticatory function is closely related to the number and distribution of teeth, although the studies varied in the number of FTUs required to maintain adequacy [12]. In their review, Azzolino et al. concluded that the masticatory function affected the number of FTUs, maximum occlusal force, and denture wearing [13]. Subsequently, using a cross-sectional study with community-dwelling older individuals, Kim found that FTUs were independently associated with masticatory function [14].

Several studies have been conducted on the relationship between decreased masticatory function associated with FTUs and nutritional ingestion among middle-aged and older individuals. El Osta et al. reported that the prosthetic type and nutritional status did not have a significant association but that the number of FTUs was significantly associated with nutritional status (OR = 2.79; 95% CI =1.49–5.22) [15]. The number of FTUs affects the intake of some nutrients and food groups. In a study conducted on 1100 community-dwelling Taiwanese older individuals, Lin et al. reported that fruits and vegetables tended to be difficult to eat as the occlusal support area of the molars decreased (P for trend, <0.05) [16]. In a 5-year cohort study, Iwasaki et al. reported that individuals who have five or fewer FTUs...
demonstrated significantly less ingestion of multiple nutrients (protein, sodium, potassium, calcium, vitamin A, vitamin E, and dietary fiber) and food groups (vegetable and meat) compared with those who have six or more \( (P < 0.05) \) [17]. These reports indicate that decreased masticatory function due to a decrease in the number of remaining teeth can cause an imbalance in ingested nutrition and food groups and lead to malnutrition.

However, masticatory function associated with reduced occlusal force can be improved by occlusal rehabilitation with prosthetic treatment. Tanasic et al. reported a significant improvement in the Mini Nutritional Assessment (MNA) scores, an indicator of nutritional status, measured before, 6 months after, and 12 months after prosthetic rehabilitation using implant-supported overdentures and removable partial dentures \( (P < 0.001) \) [18]. Moreover, Bezerra et al. conducted a meta-analysis based on 14 studies with completely edentulous individuals; they concluded that individuals wearing implant overdentures exhibited better masticatory function than conventional complete denture wearers \( (P < 0.05) \) but that the bioavailability of most nutrients remained within the same range in both groups [19]. Therefore, restoration of occlusal support by prosthetic rehabilitation, even with removable dentures, is vital to nutritional ingestion, but it alone has limits for improving nutritional status. Kossioni concluded in a review that prosthesis rehabilitation alone did not show a significant improvement in nutritional status but that its simultaneous provision with dietary guidance led to an improvements in both nutritional ingestion and imbalanced dietary intake regardless of the prosthesis type [20]. After the said review, Suzuki et al. reported that MNA Short-Form (MNA-SF) scores were significantly higher 6 months after the setting of new complete dentures in edentulous older individuals who received simple dietary advice compared with those who did not [21••]. Furthermore, the systematic review by McGowan et al., which analyzed nine studies, also supported nutritional guidance in combination with oral rehabilitation [22]. Therefore, prosthetic rehabilitation and nutritional guidance for appropriate food choice that suits the individual’s masticatory ability are crucial to improving malnutrition.

**Decreased Tongue–Lip Motor Function, Decreased Tongue Pressure, and Nutrition**

When liquid bolus enters the oral cavity, the tongue comes in contact with the soft palate and seals the oral cavity. Also, in solid foods, the tongue coordinates with the teeth, cheeks, and mandible to form a bolus and then sends it into the oropharynx. Therefore, decreased masticatory function is also closely associated with decreased tongue–lip motor function and decreased tongue pressure. In a cross-sectional study, Sagawa et al. reported that masticatory function was significantly related to the motor function of the tongue’s anterior region \( (\beta = 0.199; 95\% \text{ CI } = 1.169–43.547) \) in male older individuals and to tongue pressure \( (\beta = 0.200; 95\% \text{ CI } = 0.315–5.052) \) and the motor function of the anterior region of the tongue \( (\beta = 0.189; 95\% \text{ CI } = 1.392–33.634) \) in female older individuals [23]. Moreover, these functions are associated with aging and gradually decrease with aging, even in independent older people with good nutrition and who have >20 remaining teeth [24].

Several studies have reported that tongue pressure is related to nutritional status. Chang et al. demonstrated that the group with lower tongue pressure among community-dwelling older individuals had a higher risk of malnutrition compared with the group with higher tongue pressure \( (OR = 4.17; 95\% \text{ CI } = 0.96–18.04) \) [25]. Also, Sakai et al. reported that tongue pressure was independently associated with the MNA-SF scores in older inpatients of a rehabilitation hospital \( (\beta = 0.74; 95\% \text{ CI } = 0.12–1.35) \) [26].

Improvement of tongue–lip motor function and tongue pressure requires tongue strengthening training rather than prosthetic rehabilitation. A number of studies on the effects of tongue strengthening training on healthy individuals have been conducted. The age of the participants and training protocol vary, but all of the studies reviewed herein reported that 4 to 8 weeks of training resulted in a statistically significant improvement in tongue pressure [27–35]. In particular, the study conducted by Kito et al. found a significant improvement in tongue pressure by providing physical training and lunch containing appropriate nutrients and textured foods along with tongue strengthening training [31]. Also, Lin et al. reported that the effect of training on tongue pressure improvement manifested in the anterior tongue region in 8 weeks and in the posterior tongue region in 2 weeks [34]. Furthermore, Namiki et al. reported that tongue strengthening training improved not only tongue pressure but also tongue motor function \( (P < 0.05) \) [32], and Iyota et al. demonstrated that in addition to tongue motor function, lip motor function improved \( (P < 0.001) \) [33].

However, disagreements exist about changes in tongue pressure after detraining. Van den Steen et al. did not observe a significant decrease in tongue pressure even after 4 weeks of detraining [30]. On the other hand, Clark et al. observed significant decreases in tongue pressure after 2 to 4 weeks of detraining \( (P < 0.01) \) and no significant difference from the baseline level [28]. Also, Oh reported that tongue pressure was significantly lower after 8 weeks of training \( (P < 0.05) \) but remained significantly higher than the baseline levels \( (P < 0.05) \) after 28 weeks of detraining [29].

Few studies on whether tongue strengthening training is effective for improving nutritional status have been reported. In a 4-month intervention study conducted on nursing home residents, Kikutani et al. reported that the serum albumin
levels did not significantly differ after intervention in the group receiving supplement treatment only but significantly increased after intervention in the group receiving tongue strengthening training and supplement administration \( (P < 0.05) \) [36]. However, this study did not report whether tongue strengthening training itself could improve nutritional status. In the Cochrane Database systematic review by Baldwin et al., evidence-based reports demonstrating the effectiveness of supportive interventions in improving dietary intake for oral functions were not identified [37]. Therefore, whether oral function training alone improves nutritional status remains to be elucidated.

**Oral Dryness and Nutrition**

Food is softened by salivation until its consistency is optimal for swallowing [38]. Oral dryness is incapable of giving sufficient water to food, which makes it difficult to form a bolus. Moreover, it is closely related to the sliding of food through the esophagus and initiation of digestion procedures. In addition, another important function of saliva is taste sensitivity, which is often decreased in older age, leading to malnutrition [20].

The review by Azzolino et al. concluded that masticatory function is affected by oral dryness [13]. Also, according to the systematic review based on 15 studies by Munoz-Gonzalez et al., most of the selected studies reported that decreased salivary flow was related to food consumption (anorexia, imbalanced dietary intake, and malnutrition), although the authors could not establish a causal relationship [39]. Furthermore, in a subsequent 9-year cohort study conducted on 893 community-dwelling older individuals, Kiesswetter et al. reported that edentulous older individuals with oral dryness are at increased risk of malnutrition (hazard ratio = 2.77; 95% CI = 1.40–5.48) [40]. In a study conducted on non-acute hospitalized older patients, Ohara et al. reported that anorexia was a significant predictor of decreased salivary flow \( (OR = 2.65; 95\% CI = 1.26–5.57) \) [41]. Moreover, Spirgiene et al. demonstrated that the risk of malnutrition and malnutrition itself were associated with oral dryness \( (OR = 15.1; 95\% CI = 5.55–40.80) \) [42], and El Osta et al. reported that older individuals who were aware of oral dryness had significantly lower MNA scores \( (OR = 3.49; 95\% CI = 1.66–7.34) \) [15]. On the other hand, several studies found no association between oral dryness and nutritional status. Karawekpanyawong et al. indicated that nutritional ingestion was not significantly different between individuals with hyposalivation and those with normal salivation [8•]. Furthermore, in a study conducted on 621 community-dwelling Danish older individuals, Pedersen et al. reported that neither oral dryness nor salivary flow rates were associated with inadequate fruit and vegetable intake [43]. Moreover, in a study conducted on 1156 Swede older individuals, Lindmark et al. reported that the risk of malnutrition and malnutrition itself were not associated with oral dryness [44]. These differences in views might be due to differences in the applied method for detecting oral dryness, such as self-administered questionnaires [40], salivary flow rate \( [8, 41], \) interview [42], and inspection [44].

Two intervention studies investigated the effect of oral function training on improving oral dryness and reported conflicting results. Sugiyama et al. reported a significant increase in salivary flow as a result of oral function training for 3 months in healthy older individuals \( (P < 0.05) \) [45]. By contrast, in a study using oral function training for 6 months in independent older individuals, Sato et al. reported that there was no significant difference in salivary flow after 3 months and rather a significant decrease after 6 months compared to baseline [46]. With all these data taken together, further studies and consensus on whether oral function training affects oral dryness are still warranted.

**Deterioration of Swallowing Function and Nutrition**

Swallowing function deterioration is a condition in which feeding/swallowing function begins to decline due to aging, and it serves as the pre-stage dysfunction of obvious dysphagia [6]. Previous studies demonstrated that 11% to 68% of independent older people experience swallowing difficulties [47–49]. However, swallowing function deterioration might often be detected without complaint in older individuals [50].

Several studies on the association between the deterioration of swallowing function and malnutrition have been conducted on community-dwelling older individuals. Nishida et al. reported that deterioration swallowing function influenced nutritional status \( (OR = 4.0; 95\% CI = 1.9–8.2) \) [51]. Also, in a cross-sectional study, Yigman et al. demonstrated that the number of older individuals with malnutrition was significantly lower among those with normal swallowing function than those with deteriorated swallowing function [50]. Moreover, Spirgiene et al. reported that the risk of malnutrition and malnutrition itself were associated with deterioration of swallowing function \( (OR = 24.2; 95\% CI = 7.06–82.79) \) [42]; Lindmark et al. reported similar results \( (\beta = 1.91; 95\% CI = 1.08–3.40) \) [44]. By contrast, in a study conducted on Indian older individuals, Govind et al. reported that those with swallowing difficulties were more likely to be malnourished \( (P < 0.05) \) than those without any such difficulties, but the authors did not identify the presence of swallowing difficulties as an independent factor associated with malnutrition [52].
Some reports have indicated that tongue strengthening training is effective for improving not only tongue pressure but also swallowing function. Robbins et al. indicated that all healthy older participants in their study demonstrated significantly increased swallowing pressure after tongue strengthening training for 8 weeks [27]. In a study conducted on independent older individuals, Namiki et al. reported that the pharyngeal residue in the piriform sinus ($P = 0.022$) and pharyngeal transit times ($P = 0.004$) were smaller and shorter, respectively, after tongue strengthening training for 4 weeks [32]. On the other hand, in a 3-month intervention study conducted on patients with dysphagia, Wakabayashi et al. reported that swallowing muscle exercises involving tongue strengthening training and head flexion training did not affect dysphagia or tongue pressure [53]. Therefore, tongue strengthening training might be effective only at the stage of swallowing function deterioration, which is the pre-stage of dysphagia.

**Discussion**

This review investigated previous reports on the relationship between each symptom of oral hypofunction and malnutrition. Reduced occlusal force, oral dryness, and decreased tongue pressure were found to be associated with malnutrition. In addition, decreased masticatory function and swallowing function deterioration resulting from these symptoms being intricately intertwined with other factors were also related to malnutrition (Figure 1).

Although it is important to evaluate each oral function, a comprehensive assessment of all oral functions might also be important. Recently, numerous studies have reported that oral frailty and oral hypofunction are associated with malnutrition. Several reports about the associations between oral frailty and nutritional status have been published, but their results are inconsistent. Using the checklist proposed by the Japan Dental Association, Nomura et al. reported that oral frailty was not directly correlated with nutritional ingestion [54]. By contrast, using the criteria for oral frailty by Tanaka et al., Iwasaki et al. reported that oral frailty was closely associated with the MNA-SF scores and serum albumin levels [55] and deterioration of nutritional status ($OR = 2.24; 95\% CI = 1.08–4.63$) [56]. This inconsistency is considered to be due to the lack of clear evaluation criteria for oral frailty. On the other hand, two studies consistently demonstrated an association between nutritional status and oral hypofunction. Ohta et al. found that individuals who eat mixed diets were more likely to suffer from oral hypofunction than those who do not [57•]. Also, Nishi et al. determined that the onset of oral hypofunction was significantly and independently associated with protein intake ($OR = 1.70; 95\% CI = 1.21–2.35$) [9•].

The two intervention methods for oral function improvement are prosthetic rehabilitation and oral function training, and these have been reported to be effective for improving oral functions. However, malnutrition could not be improved by prosthetic rehabilitation alone; its management requires simultaneous provision of prosthetic rehabilitation and nutritional guidance. Furthermore, as published data on whether oral function training could improve malnutrition remain scarce, more studies should be conducted to expand the relevant literature.

This review has some limitations. First, a selection bias may have occurred as this review did not systematically search and collect reports. Second, most studies used MNA or MNA-SF to evaluate nutritional status, but one study evaluated nutritional status by body mass index measurement; therefore, the variability in evaluation methods might have affected the results. Finally, as most of the studies about oral frailty and oral hypofunction were conducted in Japan, the findings may not be applicable and generalizable to other populations.

---

**Fig. 1** Many oral functions have been reported to be associated with nutrients/malnutrition. However, there are few reports about the intervention effects of oral function on nutrients/malnutrition. This figure does not include the relationship between eating habits and oral functions.

| Deterioration of oral functions | Nutrients/malnutrition | Effect of intervention on nutrients/malnutrition |
|---------------------------------|------------------------|-----------------------------------------------|
| Masticatory function ↓ | Minerals, calcium, vitamin D, vitamin B2 ingestion ↓ [7] | Nutritional guidance is needed in prosthesis rehabilitation [20,21,22]. |
| Ocular force ↓ | Folic acid, vitamin A ↓ [8] | No report |
| Tongue–lip motor function ↓ | Protein ingestion ↓ [9] | No report |
| Tongue pressure ↓ | Malnutrition [25] | Serum albumin levels ↑ [36] |
| Low MNA-SF scores [26] | Anorexia [41], Malnutrition [42] | No report |
| Oral dryness | Low MNA-SF scores [15] | No report |
| Not associated with malnutrition [44] | Malnutrition [42,51] | No report |
Numerous unclarified points about the deterioration of oral functions and malnutrition remain. In the future, detailed research should be conducted to elucidate the causal relationship between oral function deterioration and malnutrition and to develop oral function intervention methods for malnutrition improvement.

Conclusions

Oral function deterioration is significantly associated with malnutrition. Prosthetic rehabilitation and oral function training have been reported to effectively improve these functions. Malnutrition could not be improved by prosthetic rehabilitation alone; however, it might be improved by the simultaneous provision of prosthetic rehabilitation and nutritional guidance. Furthermore, whether oral function training alone improves nutritional status still needs to be elucidated.

Acknowledgements

The authors would like to thank Professor Haruhiko Kashiwazaki and the staff members of the Section of Geriatric Dentistry and Perioperative Medicine in Dentistry, Division of Maxillofacial Diagnostic and Surgical Science, Faculty of Dental Science, Kyushu University, for their guidance in writing the review.

Author Contribution

Conceptualization: K.I., S.M.; data curation, investigation, and writing-original draft: K.I.; funding acquisition and writing-review and editing: S.M. The authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by JSPS KAKENHI Grant Number JP 20K18636.

Declarations

Institutional Review Board Statement

Not applicable.

Human and Animal Rights and Informed Consent

Not applicable.

Conflict of Interest

The authors declare no competing interests.

Open Access

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/

References

Papers of particular interest, published recently, have been highlighted as:

● Of importance

●● Of major importance

1. Sumi Y, Miura H, Nagaya M, Nagaosa S, Umemura O. Relationship between oral function and general condition among Japanese nursing home residents. Arch Gerontol Geriatr. 2009;48:100–5.

2. Hagglund P, Falt A, Hagg M, Wester P, Jäghagen EL. Swallowing dysfunction as risk factor for undernutrition in older people admitted to Swedish short-term care: a cross-sectional study. Aging Clin Exp Res. 2019;31:85–94.

3. Takahashi K, Amemiya K, Nakatsuka M, Nakamura K, Kasai M, Meguro I. Impaired eating and swallowing function in older adults in the community: the Kurilhara project. Int J Environ Res Public Health. 2019. https://doi.org/10.3390/ijerph16204040.

4. Komiyama T, Ohi T, Miyoshi Y, Tomata Y, Zhang S, Tsubi I, et al. Verification of the criteria for reduced occlusal force to diagnose oral hypofunction in older Japanese people: A prospective cohort study on incident functional disability. J Oral Rehabil. 2020;47:989–97.

5. Umemoto G, Furuya H, Tsuboi Y, Fujioka S, Arakata H, Sugahara M, et al. Characteristics of tongue and pharyngeal pressure in patients with neuromuscular diseases. Degener Neuromuscul Dis. 2017;7:71–8.

6. Minakuchi S, Tsuga K, Ikbe K, Ueda T, Tamura F, Nagao K, et al. Oral hypofunction in the older population: Position paper of the Japanese Society of Gerodontology in 2016. Gerodontology. 2018;35:317–24.

7. Bori FK, Fukuhara M, Masaki C, Ohta Y, Nakamichi I, Sakata S, et al. The relationship between masticatory performance and intakes of foods and nutrients in Japanese male workers: a cross-sectional study. J Oral Rehabil. 2020;47:1142–9. This study has reported that masticatory function is associated with the intake of some nutrients and foods.

8. Karawekpanyawong R, Nohno K, Kubota Y, Ogawa H. Oral health and nutritional intake in community-dwelling 90-year-old Japanese people: a cross-sectional study. Gerodontology. 2022. https://doi.org/10.1111/ger.12627. This study has reported that masticatory function is associated with some nutritional intake, but not with salivation.

9. Nishi K, Kanouchi H, Tanaka A, Nakamura M, Hamada T, Mishima Y, et al. Relationship between oral hypofunction, and protein intake: a cross-sectional study in local community-dwelling adults. Nutrients. 2021. https://doi.org/10.3390/nu1324377. This study has reported that occlusal force and the onset of oral hypofunction were associated with protein intake.

10. Wakai K, Naito M, Naito T, Kojima M, Nakagaki H, Umemura O, et al. Tooth loss and intakes of nutrients and foods: a nationwide survey of Japanese dentists. Commun Dent Oral Epidemiol. 2010;38:43–9.

11. Nakamura M, Ojima T, Nagahata T, Kondo I, Nomiyama T, Yoshita K, et al. Having few remaining teeth is associated with a low nutrient intake and low serum albumin levels in middle-aged and older Japanese individuals: findings from the NIPPON DATA2010. Environ Health Prev Med. 2019. https://doi.org/10.1186/s12199-018-0752-x.

12. Naka O, Anastassiadou V, Pissiotis A. Association between functional tooth units and chewing ability in older adults: a systematic review. Gerodontology. 2014;31:166–77.
13. Azzolini D, Passarelli PC, De Angelis P, Piccirillo GB, D’Addona A, Cesari M. Poor Oral Health as a Determinant of Mortality: A Systematic Review of Longitudinal Studies. J Oral Rehabil. 2020;47(7):581-93. https://doi.org/10.1111/joor.13107.

14. Kim HE. Influential factors of masticatory performance in older adults: a cross-sectional study. J Int Environ Res Public Health. 2021. https://doi.org/10.3390/ijerph18084286.

15. El Osta N, Hennequin M, Tubert-Jeannin S, Naaman NBA, El Osta L, Geaehan N. The pertinence of oral health indicators in nutritional studies in the elderly. Clin Nutr. 2014;33:316–21.

16. Lin YC, Du JK, Lin PC, Kabasawa Y, Lin PL, Hsiao SY, et al. Association between the dental occlusion and perceived ability to eat foods of Taiwanese older adults. J Oral Rehabil. 2021;48:817–26.

17. Iwasaki M, Yoshihara A, Ogawa H, Sato M, Muramatsu K, Watanabe R, et al. Longitudinal association of dentition status with dietary intake in Japanese adults aged 75 to 80 years. J Oral Rehabil. 2016;43:737–44.

18. Tanasic I, Radakovic T, Tihaček-Sojic L, Milic-Lemic A. Effect of prosthetic rehabilitation on nutritional status in older adults. Top Clin Nutr. 2017;32:330–9.

19. Bezerra AP, Gama LT, Pereira LJ, van der Bilt A, Peyron MA, Garcia R, et al. Do implant-supported prostheses affect bioavailability of nutrients of complete and partially edentulous patients? A systematic review with meta-analysis. Clin Nutr. 2021;40:3235–49.

20. Kossioni AE. The association of poor oral health parameters with malnutrition in older adults: a review considering the potential implications for cognitive impairment. Nutrients. 2018. https://doi.org/10.3390/nu10111709.

21. Suzuki H, Kanazawa M, Komagamine Y, Iwaki M, Amagai N, Minakuchi S. Changes in the nutritional statuses of edentulous elderly patients after new denture fabrication with and without providing simple dietary advice. J Prosthodont Res. 2019;63:288–92. This study has reported that prosthetic rehabilitation in combination with nutritional guidance significantly improved nutritional status.

22. McGowan L, McCrum LA, Watson S, Cardwell C, McGuinness B, Rutherford H, et al. The impact of oral rehabilitation coupled with healthy dietary advice on the nutritional status of adults: A systematic review and meta-analysis. Crit Rev Food Sci Nutr. 2020;60:2127–47.

23. Sagawa K, Furuya H, Ohara Y, Yoshida M, Hirano H, Iijima K, et al. Tongue function is important for masticatory performance in the healthy elderly: a cross-sectional survey of community-dwelling elderly. J Prosthodont Res. 2019;63:31–4.

24. Iyota K, Mizutani S, Kishimoto H, Oku S, Tani A, Yatsugi H, et al. Effects of isometric tongue lifting exercise on oral function, physical function, and body composition in community-dwelling older individuals: a pilot study. Gerontology. 2021. https://doi.org/10.1159/000518270.

25. Lin CH, Chung SY, Lin CT, Hwu YJ. Effect of tongue-to-palate resistance training on tongue strength in healthy adults. Auris Nasus Larynx. 2021;48:116–23.

26. Yano J, Nagami S, Yokoyama T, Nakamura K, Kobayashi M, Odan Y, et al. Effects of tongue-strengthening self-exercises in healthy older adults: a non-randomized controlled trial. Dysphagia. 2021;36:925–35.

27. Kikutani T, Enamoto R, Tamura F, Oyaizu K, Suzuki A, Inaba S. Effects of oral functional training for nutritional improvement in Japanese older people requiring long-term care. Gerontology. 2006;23:93–8.

28. Baldwin C, Kimber KL, Gibbs M, Weekes CE. Supportive interventions for enhancing dietary intake in malnourished or nutritionally at-risk adults. Cochrane Database Syst Rev. 2016. https://doi.org/10.1002/14651858.CD009840.pub2.

29. Matsuo K, Palmer JB. Anatomy and physiology of feeding and swallowing: normal and abnormal. Phys Med Rehabil Clin N Am. 2008;19:691–707.

30. Munoz-Gonzalez C, Vandenberghe-Descamps M, Feron G, Canon F, Laboure H, Sulmont-Rosse C. Association between salivary hypofunction and food consumption in the elderly: a systematic literature review. J Nutr Health Aging. 2018;22:407–19.

31. Kiesswetter E, Hengeveld LM, Keijser BJF, Volkert D, Visser M. Nutritional status of rural community-dwelling older people and oral health determinants of incident malnutrition in community-dwelling older adults. J Dent. 2019;85:73–80.

32. Oh JC. Effects of tongue strength training and detraining on tongue pressures in healthy adults. Dysphagia. 2015;30:315–20.

33. Van den Steen L, Schellen C, Verstraelen K, Beeckman AS, Vandenbroucke J, De Bodt M, et al. Tongue-strengthening exercises in healthy older adults: specificity of bulb position and detraining effects. Dysphagia. 2018;33:337–44.

34. Kito N, Matsuo K, Ogawa K, Izumi A, Kishima M, Itoda M, et al. Positive effect of “textured lunches” gatherings and oral exercises combined with physical exercises on oral and physical function in older individuals: a cluster randomized controlled trial. J Nutr Health Aging. 2019;23:669–76.

35. Namiki C, Haru K, Tohara H, Kobayashi K, Chantaramanee A, Nakagawa K, et al. Tongue-pressure resistance training improves tongue and suprathyroid muscle functions simultaneously. Clin Interv Aging. 2019;14:601–8.

36. Iyota K, Mizutani S, Kishimoto H, Oku S, Tani A, Yatsugi H, et al. Effect of isometric tongue lifting exercise on oral function, physical function, and body composition in community-dwelling older individuals: a pilot study. Gerontology. 2021. https://doi.org/10.1159/000518270.

37. Lin CH, Chung SY, Lin CT, Hwu YJ. Effect of tongue-to-palate resistance training on tongue strength in healthy adults. Auris Nasus Larynx. 2021;48:116–23.

38. Yano J, Nagami S, Yokoyama T, Nakamura K, Kobayashi M, Odan Y, et al. Effects of tongue-strengthening self-exercises in healthy older adults: a non-randomized controlled trial. Dysphagia. 2021;36:925–35.

39. Kikutani T, Enamoto R, Tamura F, Oyaizu K, Suzuki A, Inaba S. Effects of oral functional training for nutritional improvement in Japanese older people requiring long-term care. Gerontology. 2006;23:93–8.

40. Baldwin C, Kimber KL, Gibbs M, Weekes CE. Supportive interventions for enhancing dietary intake in malnourished or nutritionally at-risk adults. Cochrane Database Syst Rev. 2016. https://doi.org/10.1002/14651858.CD009840.pub2.

41. Matsuo K, Palmer JB. Anatomy and physiology of feeding and swallowing: normal and abnormal. Phys Med Rehabil Clin N Am. 2008;19:691–707.

42. Munoz-Gonzalez C, Vandenberghe-Descamps M, Feron G, Canon F, Laboure H, Sulmont-Rosse C. Association between salivary hypofunction and food consumption in the elderly: a systematic literature review. J Nutr Health Aging. 2018;22:407–19.

43. Kiesswetter E, Hengeveld LM, Keijser BJF, Volkert D, Visser M. Nutritional status of rural community-dwelling older people and oral health determinants of incident malnutrition in community-dwelling older adults. J Dent. 2019;85:73–80.

44. Oh JC. Effects of tongue strength training and detraining on tongue pressures in healthy adults. Dysphagia. 2015;30:315–20.

45. Van den Steen L, Schellen C, Verstraelen K, Beeckman AS, Vandenbroucke J, De Bodt M, et al. Tongue-strengthening exercises in healthy older adults: specificity of bulb position and detraining effects. Dysphagia. 2018;33:337–44.

46. Kito N, Matsuo K, Ogawa K, Izumi A, Kishima M, Itoda M, et al. Positive effect of “textured lunches” gatherings and oral exercises combined with physical exercises on oral and physical function in older individuals: a cluster randomized controlled trial. J Nutr Health Aging. 2019;23:669–76.

47. Namiki C, Haru K, Tohara H, Kobayashi K, Chantaramanee A, Nakagawa K, et al. Tongue-pressure resistance training improves tongue and suprathyroid muscle functions simultaneously. Clin Interv Aging. 2019;14:601–8.

48. Iyota K, Mizutani S, Kishimoto H, Oku S, Tani A, Yatsugi H, et al. Effect of isometric tongue lifting exercise on oral function, physical function, and body composition in community-dwelling older individuals: a pilot study. Gerontology. 2021. https://doi.org/10.1159/000518270.

49. Lin CH, Chung SY, Lin CT, Hwu YJ. Effect of tongue-to-palate resistance training on tongue strength in healthy adults. Auris Nasus Larynx. 2021;48:116–23.

50. Yano J, Nagami S, Yokoyama T, Nakamura K, Kobayashi M, Odan Y, et al. Effects of tongue-strengthening self-exercises in healthy older adults: a non-randomized controlled trial. Dysphagia. 2021;36:925–35.
45. Sugiyama T, Ohkubo M, Honda Y, Tasaka A, Nagasawa K, Ishida R, et al. Effect of swallowing exercises in independent elderly. Bull Tokyo Dent Coll. 2013;54:109–15.

46. Sato M, Sugimoto M, Yamamoto Y, Saruta J, Tsukinoki K. Effect of oral functional training on immunological abilities of older people: a case control study. BMC Oral Health. 2018. https://doi.org/10.1186/s12903-017-0461-7.

47. Bloem BR, Lagaay AM, Vanbeek W, Haan J, Roos RAC, Wintzen AR. Prevalence of Subjective Dysphagia in Community Residents Aged Over 87. Br Med J. 1990;300:721–2.

48. Holland G, Jayasekeran V, Pendleton N, Horan M, Jones M, Hamdy S. Prevalence and symptom profiling of oropharyngeal dysphagia in a community dwelling of an elderly population: a self-reporting questionnaire survey. Dis Esophagus. 2011;24:476–80.

49. Dionyssiotis Y, Chhetri JK, Piotrowicz K, Gueye T, Sanchez E. Impact of nutrition for rehabilitation of older patients: report on the 1st EICA-ESPRM-EUGMS Train the Trainers Course. Eur Geriatr Med. 2017;8:183–90.

50. Yigman ZA, Umay E, Cankurtaran D, Guzel S. Swallowing difficulty in the older adults: presbyphagia or dysphagia with sarcopenia? Int J Rehabil Res. 2021;44:336–42.

51. Nishida T, Yamabe K, Honda S. The influence of dysphagia on nutritional and frailty status among community-dwelling older adults. Nutrients. 2021. https://doi.org/10.3390/nu13020512.

52. Govind R, Rajeav J, Bhatt AN. Malnutrition among community dwelling older adults in a rural block area of South India. J Fam Med Prim Care. 2020;9:5982–7.

53. Wakabayashi H, Matsushima M, Momosaki R, Yoshida S, Mutai R, Yodoshi T, et al. The effects of resistance training of swallowing muscles on dysphagia in older people: A cluster, randomized, controlled trial. Nutrition. 2018;48:111–6.

54. Nomura Y, Ishii Y, Suzuki S, Morita K, Suzuki A, Tanabe J, et al. Nutritional status and oral frailty: a community based study. Nutrients. 2020. https://doi.org/10.3390/nu12092886.

55. Iwasaki M, Motokawa K, Watanabe Y, Shirobe M, Inagaki H, Edahiro A, et al. Association between oral frailty and nutritional status among community-dwelling older adults: the Takashimadaira study. J Nutr Health Aging. 2020;24:1003–10.

56. Iwasaki M, Motokawa K, Watanabe Y, Shirobe M, Inagaki H, Edahiro A, et al. A two-year longitudinal study of the association between oral frailty and deteriorating nutritional status among community-dwelling older adults. Int J Environ Res Public Health. 2021. https://doi.org/10.3390/ijerph18010213.

57. Ohta M, Imamura Y, Chebib N, Schulte-Eickhoff RM, Allain S, Genton L, et al. Oral function and nutritional status in non-acute hospitalised elders. Gerodontology. 2021;39:74–82. This report has reported that individuals who eat mixed diets were more likely to suffer from oral hypofunction than those who do not.

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.