Public Health Nutrition: 21(10), 1886–1903 doi:10.1017/S1368980017004244

Review Article

Functional determinants of dietary intake in community-dwelling older adults: a DEDIPAC (DEterminants of DIet and Physical ACtivity) systematic literature review

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Submitted 2 April 2017: Final revision received 28 November 2017: Accepted 14 December 2017: First published online 12 February 2018

Abstract

Objective: The identification of determinants of dietary intake is an important prerequisite for the development of interventions to improve diet. The present systematic literature review aimed to compile the current knowledge on individual functional determinants of dietary intake in community-dwelling older adults.
Design: A systematic search was performed in PubMed, Scopus, Web of Science and the Cochrane Library. Titles, abstracts and full texts were screened according to predefined inclusion and exclusion criteria. Studies were included when focusing on dietary intake as an outcome and on chemosensory, oral, cognitive or physical function as a determinant.
Setting: Community.
Subjects: Older adults at least 65 years old without acute or specific chronic diseases.
Results: From initially 14 585 potentially relevant papers, thirty-six were included. For chemosensory, cognitive and physical function only a few papers were found, which reported inconsistent results regarding the relationship to dietary intake. In contrast, oral function was extensively studied (*n* 31). Different surrogates of oral function like dental status, number of teeth, bite force or chewing problems were associated with food as well as nutrient intakes including fibre. As all except six studies had a cross-sectional design, no causal relationships could be derived.
Conclusions: Among functional determinants of dietary intake oral factors are well documented in older adults, whereas the role of other functional determinants remains unclear and needs further systematic research.

Keywords:
Dietary intake
Function
Determinants
Older adults
Community-dwelling

Currently about 18 % of the population in Europe is at least 65 years old(1). Albeit that health problems and care dependency occur more frequently with increasing age, most older people live in the community(1) and manage their food supply by themselves.

Nutrition is a main contributor to health, well-being and quality of life in older age. Several studies have shown beneficial effects of the intake of certain nutrients as well as of certain dietary patterns, like the Mediterranean diet, on frailty, physical and cognitive function in older

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adults[2–6]. Conversely, an unbalanced or an inadequate diet can result in undernutrition or obesity. Both are risk factors for adverse clinical outcomes including functional decline and mortality[7–11]. Depending on definitions and sampling aspects, prevalence rate up to 22 % has been reported for undernutrition in community-dwelling older adults living in Europe[12–16]. Obesity is prevalent in about 18 %[17]. As the total number and proportion of older people will increase further[1], preventive and therapeutic strategies reducing the prevalence of undernutrition and obesity become important public health issues.

In older people both unbalanced dietary patterns and inadequate intakes of energy and nutrients are frequently reported[18–20]. As dietary intake is influenced by an interplay of multiple individual, intra-individual, environmental and political factors[21], it is necessary to identify relevant and modifiable factors to implement adequate preventive approaches. In older adults, on the individual level, functional factors are of interest as the ageing process is accompanied by numerous functional changes on different levels[22–26]. Factors like declining chemosensory function, chewing and swallowing difficulties, physical limitations of the upper and lower extremities and cognitive impairments impede shopping, cooking and eating, may reduce the attractiveness of meals and may consequently influence dietary intake.

However, it is currently unclear which of these factors indeed affect dietary intake, if the associations are only correlational or causal, and if knowledge gaps exist.

The present systematic literature review aimed to compile the current knowledge on individual functional (chemosensory, oral, cognitive and physical) determinants of dietary intake in community-dwelling older adults. The work is part of the DEDIPAC (DEterminants of DIet and Physical ACtivity) knowledge hub (Thematic Area 2), focusing on determinants of diet across the life course[27].

Methods

The procedure of the current systematic literature review was documented according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[28].

Literature search

In February 2015 a systematic search was performed in PubMed, Scopus, Web of Science and the Cochrane Library to identify relevant studies on functional determinants of dietary intake in community-dwelling older adults. In August 2017 the search was updated. Additionally, reference lists of the included studies and of one systematic literature review on mastication and dietary intake in older adults[29] were screened for relevant papers. To define the search terms of the different fields we focused on theoretical models and frameworks, studies dealing with the respective topics, keywords and MeSH (medical subject heading) terms from the searched databases, and expertise of the working group members. The search strategy was documented in a study protocol and combines terms of the following fields: outcome (e.g. ‘dietary intake’), sample (e.g. ‘older adults’ and ‘community-dwelling’), description of the kind of association (e.g. ‘determinant’, ‘correlate’) and determinant (‘chemosensory’, ‘oral’, ‘cognitive’, or ‘physical’ function). The detailed search strategy can be found in the online supplementary material, Supplemental File 1.

Study selection

The study selection was based on predefined inclusion and exclusion criteria. Regarding the study population, only studies with participants at least 65 years of age, not being acutely ill and living in the community were included. Studies which focused solely on specific diseases or which were conducted in the hospital or the nursing home setting were excluded. These criteria were chosen to collect data representative and specific for the old age group. Therefore, studies with a mean sample age of 65 years or older but including younger individuals were not considered, as in the younger part of the sample different aspects (e.g. working conditions) determine behaviour than can be expected for the retired older population.

There were no restrictions regarding the study design and the publication year. Only publications in English language were considered and grey literature in book chapters, reports and conference abstracts were excluded.

After excluding duplicates, the study selection was performed in a three-step procedure. Titles, abstracts and full texts were screened by two independent reviewers. In cases of disagreement regarding the inclusion, a third reviewer was consulted. The titles, abstracts and full texts were distributed among the working group members according to their expertise: C.S.-R., L.M.D., E.P. and S.M. were responsible for oral and chemosensory determinants; C.F., L.M.D., E.P. and S.M. worked on cognitive determinants; and A.Sa., D.C., F.S., E.M., A.P. and E.K. conducted the screening for physical determinants. E.K. and D.V. acted as third reviewers to solve disagreements.

Data extraction

For the included papers, besides general article information (authors, title, year, citation), data regarding the studies’ characteristics (objective, study design, sample size, inclusion and exclusion criteria) and participants’ characteristics (mean age or age range, percentage female gender, country/ethnicity, health/functional status) were extracted. Moreover, information on the determinants and outcomes (name and assessment method) used in the respective studies and the main results were summarized. To describe the associations between functional determinants and dietary outcomes, correlation coefficients,

β coefficients, OR with CI and P values were extracted. Data extraction was conducted in duplicate. E.K. summarized the data extraction tables, and the results were confirmed by the systematic literature review group.

Quality assessment

Quality assessment of the reviewed studies was guided by the tool of Kmet *et al.*[30]. The description and appropriateness of eleven criteria on research question, study design, subject selection, subject characteristics, outcome measures, sample size, analytical approach, estimate of variance, confounder control, study results and conclusions were evaluated. Each criterion was rated with 'yes', 'partial' or 'no'. The summary score was calculated as follows: [(number of 'yes' × 2) + (number of 'partial' × 1)]/(total possible sum − number of 'not applicable' × 2). Higher scores indicate a better quality, with a score of 1 representing fulfilling all quality criteria. The quality assessment was conducted by two independent reviewers for each study. In cases of disagreement, the issues were solved by the mediation of E.K. as a third reviewer.

Results

Study selection

Figure 1 provides an overview of the screening and selection process. The systematic search resulted in 25 319 hits and seventeen studies were found by additional sources. After removing duplicates, 14 585 studies were eligible for the title screening. During the title screening 13 730 studies were excluded for not matching the inclusion criteria; thus 855 potentially relevant studies were included in the abstract screening. During the abstract screening a further 754 studies were excluded. Accordingly, full-text screening was performed with 101 studies. As a further sixty-four articles had to be excluded and two publications on oral determinants[31,32] reporting the same results were counted as one study, the selection process resulted in thirty-six publications.

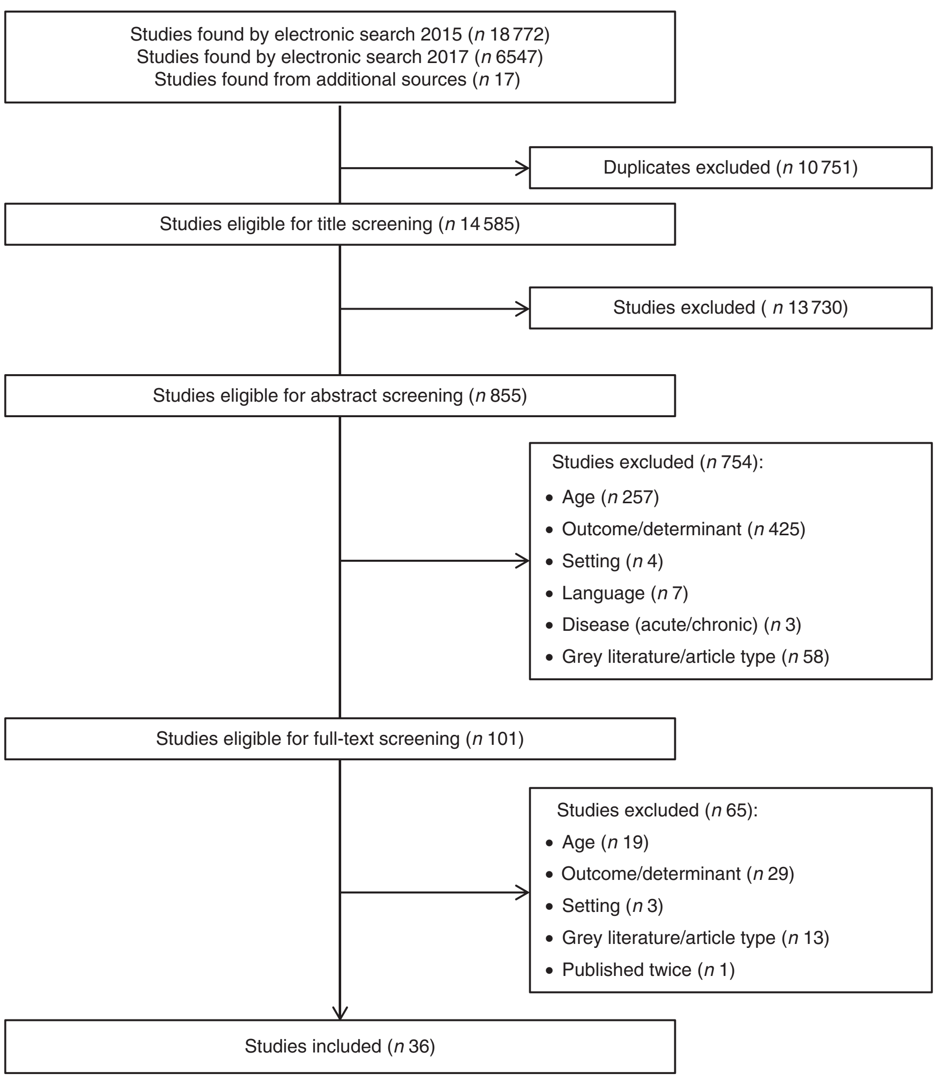

Fig. 1 Flowchart describing the process of study selection for the present systematic literature review on functional determinants of dietary intake in community-dwelling older adults

https://doi.org/10.1017/S1368980017004244 Published online by Cambridge University Press

Studies' and participants' characteristics

Table 1 presents an overview of the main studies' and participants' characteristics. Of the thirty-six considered studies, nine were published before 2000 and thirteen studies were published after 2010. Thirty studies were cross-sectional and six had a longitudinal design. Most studies were conducted in Asia (*n* 13) followed by North America (*n* 11) and Europe (*n* 10). Only one study was conducted in Africa (*n* 1) and one study combined data from Europe and the USA (Table 1).

Sample sizes range from fifty-seven to 5073 participants with twelve studies including at least 1000 participants and five studies with fewer than 100 participants (Table 1). The studies varied regarding the inclusion and exclusion criteria, some using only few and rough criteria like age, while others used very specific criteria like the absence of cognitive or physical functional limitations or specific diseases (see online supplementary material, Supplemental File 2).

Most of the studies included both genders, two studies focused solely on women, two solely on men and three further studies did not report on gender (Table 1). The mean age was not presented in all studies. Only three studies reported a mean age of at least 80 years, while in most studies the mean age was between 70 and 79 years (Table 1).

In twenty-three studies health and functional status of the participants was not characterized. Participants of the other studies were mostly free of major functional limitations or health complaints (Table 1).

Outcome

Regarding the outcomes, sixteen studies focused on energy and/or nutrient intakes (macronutrients, micronutrients, fibre), five studies on food intakes, and eight studies on the combination of food and nutrient intakes. Further, seven studies used scores to describe dietary quality or diversity (Table 2). Methods to assess the outcome comprised 24 h recalls (*n* 10), FFQ (*n* 4), simple food lists (*n* 4), estimated dietary records (*n* 1), diet history questionnaires (*n* 10), weighing protocols (*n* 3), or combinations of methods (*n* 4; Table 2).

Quality of the studies

The quality scores ranged from 0·14 to 1·00, with four studies fulfilling all criteria sufficiently. Fifteen studies had a score > 0·90 indicating a low risk of bias. Eleven studies reached a score between 0·75 and 0·90 and a further five studies between 0·64 and < 0·75. Only one study met less than half of the considered quality criteria. The mean quality scores of the studies were similar between the different determinant domains: chemosensory function (0·89), oral function (0·86), cognitive function (0·89) and physical function (0·90). Methodological shortcomings were mostly identified regarding confounder control (*n* 21), description of subjects' characteristics (*n* 21) and definition of outcomes (*n* 11). The quality criteria on study objective (*n* 3), study design (*n* 2) and conclusion (*n* 0) were most often fulfilled. The sum score of the quality assessment is shown in Table 1 and details are presented in the online supplementary material, Supplemental File 3.

Chemosensory function

Regarding chemosensory function two cross-sectional studies were identified[33,34]. The first study evaluated olfactory function by objective tests on odour thresholds and odour identification and investigated the association with food and nutrient intakes[33] (Table 2). Only bivariate correlations were presented. Regarding food intakes, most correlations between both odour and flavour perception and the respective food groups were not significant. Regarding nutrient intakes, some low but significant correlations between odour perception and measures of fat intake were found (all correlation coefficients < 0·35; Table 2). The second study did not identify self-reported ability to taste and smell as a predictor of diet variety (Table 2)[34].

Oral function

Thirty-one studies were identified examining oral factors in relation to dietary intake in community-dwelling older adults[31,32,34–63]. Regarding the outcome, most of the studies focused on the intakes of micro- and macronutrients (*n* 21) and dietary fibre (*n* 10). Further outcome measures were the intake of certain foods (*n* 11), food diversity (*n* 3) and dietary quality (*n* 4; Table 2).

As oral factors general aspects of oral health like number of teeth, dental status (inadequate *v.* adequate), caries or wearing dentures were investigated (*n* 22). Additionally, some studies focused on functional aspects by assessing chewing ability and bite force (*n* 17). Only one study considered also the aspect of swallowing function as a component of an oral health indicator[63] (Table 2).

Thirteen studies used dental examinations or objective tests to evaluate oral factors, thirteen studies were questionnaire-based, and five studies used combinations of dental examinations and self-reports (Table 2).

Regarding dental status, thirteen out of seventeen studies reported that edentulous subjects and those with inadequate dental status had lower intakes of certain foods and nutrients compared with those with adequate dental status or dentures[31,32,35–45,60]. Moreover, tooth count was associated with dietary intake in five of six studies[31,32,38,46–49]. Five studies investigated differences in the intakes of foods and nutrients between groups wearing different types of dentures (e.g. fixed dentures or removable dentures)[41,48,50–52]. Only Tsai and Chang reported differences between fixed, removable and no denture wearers in some of the investigated food groups[52]. However, no clear trend favouring a certain denture type was visible (Table 2).

Of the fourteen studies focusing on chewing ability or chewing problems[41,43,45,50,52–54,56–62], four showed no

https://doi.org/10.1017/S1368980017004244 Published online by Cambridge University Press

Table 1 Characteristics of the studies and participants included in the present systematic literature review on functional determinants of dietary intake in community-dwelling older adults

Reference	Study design*	Sample size (*n*)	Country/ethnicity	Age† (years)	Female (%)	Health/functional status	Quality score‡
Chemosensory function							
Duffy *et al.* (1995)[33]	CS	80	USA	76 (SD 6)	100	Moderately impaired functional status or better	0·86
Oral function							
Apollonio *et al.* (1997)[35]	CS	1137	Italy	70–75	67	NR	0·91
Bailey *et al.* (2004)[63]	LS (1 year)	147	USA	Mean: 73	NR	NR	0·77
Fontijn-Tekamp *et al.* (1996)[41]	CS	1424	Belgium, Denmark, France, Italy, Netherlands, Portugal, Spain, Switzerland, USA, Northern Ireland, Poland	74–79	53	NR	0·77
Han and Kim (2016)[36]	CS	1168	South Korea	75·1 (SD 6·1)	62	NR	0·91
Inomata *et al.* (2014)[46]	CS	757	Japan	70·1 (SD 0·9)	51	NR	0·91
Iwasaki *et al.* (2014)[42]	CS	353	Japan	all 80	51	NR	1·00
Iwasaki *et al.* (2016)[40]	LS (5 years)	286	Japan	all 75	50	49 % of the participants had a decreased ADL at baseline	1·00
Kim *et al.* (2017)[47]	CS	686	South Korea	65–69: 26 % 70–74: 35 % 75–79: 23 % ≥ 80: 16 %	59	NR	0·73
Kimura *et al.* (2013)[53]	CS	269	Japan	80·6 (SD 4·7)	67	NR	0·86
Kwon *et al.* (2017)[56]	CS	999	Korea	≥ 65	58	NR	0·86
Lee *et al.* (2014)[37]	CS	3075	USA, 42 % Black	White dentate: 73·8 (SD 0·1) White edentate: 73·8 (SD 0·2) Black dentate: 73·8 (SD 0·1) Black edentate: 73·3 (SD 0·1)	52	Self-reported poor health status: White edentate, 18 %; White dentate, 7 %; Black edentate, 34 %; Black dentate, 24 %	1·00
Liedberg *et al.* (2004)[51]	CS	84	Sweden	67–68	0	NR	0·73
Liedberg *et al.* (2007)[50]	CS	481	Sweden	67–68	0	NR	0·95
Lin *et al.* (2010)[54]	CS	103	Taiwan	≥ 65	34	NR	0·14
Marcenes *et al.* (2003)[38]	CS	753	UK	≥ 65	NR	NR	0·77
Marshall *et al.* (2002)[48]	CS	220	USA	84·7 (SD 3·9)	67	96 % had no intellectual impairment	0·91
Nordström (1990)[43]	CS	183	Sweden	74·6	49	NR	0·86
Österberg and Steen (1982)[44]	CS	368	Sweden	all 70	51	NR	0·82
Österberg *et al.* (2002)[39]	CS	160	Sweden	all 80	54	NR	0·91
Sheiham *et al.* (2001)[31,32]	CS	753	UK	≥ 65	NR	NR	0·86
Tsai and Chang (2011)[52]	CS	2766	Taiwan	65–74: 57 % ≥ 75: 43 %	45	90 % of men, 85 % of women had no ADL dependency	0·91
Woo *et al.* (1994)[57]	CS	1616	Hong Kong	NR	46	NR	0·86
Yoshida *et al.* (2011)[55]	CS	182	Japan	Retained contact: 74·4 (SD 3·6) Lost contact: 77·0 (SD 5·3)	67	NR	0·64
Yoshihara *et al.* (2005)[49]	CS	57	Japan	all 74	46	Did not require special care for their daily activities	0·91
Cognitive function							
de Rouvray *et al.* (2014)[65]	CS	1016	Central Africa	73·6 (SD 6·5)	59	33 % some, 14 % major difficulties doing housework	0·91
Shatenstein *et al.* (2007)[64]	LS (1 year; case–control)	94	Canada	Cases: 77·8 (SD 4·6) Controls: 73·7 (SD 5·5)	Cases: 61 Controls: 78	NR	0·64
Physical function							
Sarti *et al.* (2013)[66]	LS (3 years)	92	Italy	70·9 (SD 4·0)	100	Healthy condition; attending physical activity programmes regularly; baseline SPPB = 10·3 (SD 1·8)	0·95
Bianchetti *et al.* (1990)[67]	CS	1201	Italy	70–75	68	25 % of subjects had at least one IADL limitation	0·64

Table 1 *Continued*

Reference	Study design*	Sample size (*n*)	Country/ethnicity	Age† (years)	Female (%)	Health/functional status	Quality score‡
Multiple functional domains							
Dean *et al.* (2009)[34]	CS	1484	Sweden, Denmark, Germany, Poland, UK, Italy, Spain, Portugal	≥65	~50	NR	0·91
Holmes and Roberts (2011)[61]	CS	725	UK	65–74: 48 % ≥75: 52 %	68	NR	0·95
Keller *et al.* (1997)[45]	CS	5073	Canada	72·7	60	12 % with walking difficulties, 6 % with difficulties in basic self-care	0·86
Kwon *et al.* (2006)[59]	LS (8 years)	417	Japan	70·4 (SD 4·5)	62	4·8 (SD 0·6) out of 5 IADL points	0·95
Posner *et al.* (1994)[60]	CS	1156	USA	70–98	57	84 % physically limited, 5 % mentally disoriented	0·91
Shatenstein *et al.* (2013)[58]	CS	1793	Canada	67–84	52	Good general health, cognitively and functionally intact	0·95
Shatenstein *et al.* (2016)[62]	LS (3 years)	373	Canada	74·0 (SD 4·0)	57	NR	1·00

CS, cross-sectional study; LS, longitudinal study; NR, not reported; ADL, activities of daily living; SPPB, Short Physical Performance Battery; IADL, instrumental activities of daily living.
*CS or LS.
†Mean and SD, or percentage, or inclusion age.
‡Sum score of the quality assessment according to Kmet *et al.*[30].

association with food/nutrient intakes or diet quality[50,57,60,62] and two did not report the results[41,52]. All other studies observed lower intakes of at least certain foods or nutrients as well as lower dietary quality in those with chewing problems compared with those without chewing problems (Table 2). In an 8-year follow-up study, deterioration of chewing ability was identified as an important predictor of a decline in dietary variety (OR = 3·31; 95 % CI 1·36, 8·08)[59], while a 3-year follow-up study did not identify chewing ability as a predictor of change in diet quality[62].

In both studies investigating bite force, this factor was consistently related to fibre and vegetable intakes[39,46]. The study summarizing multiple oral health problems, including swallowing function, showed a negative modification of micronutrient and fibre intakes but not of macronutrient intakes (Table 2)[63].

Cognitive function

Eight studies (five cross-sectional and three longitudinal) investigating cognitive function as a determinant of dietary intake were found[34,45,58–60,62,64,65] (Tables 1 and 2). The two studies focusing on dementia diagnosed by DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, 4th ed.) criteria and by a neuropsychological test battery showed lower intakes of certain foods in demented compared with non-demented participants[64,65]. The study by Shatenstein *et al.* used a longitudinal case–control design[64] while the study of de Rouvray *et al.* was cross-sectional and presented only unadjusted results[65]. In another study based on a subjective judgement of cognitive status by the interviewer, no association between cognitive function and a nutrient inadequacy score was found[60]. However, in that study, only a small part of the sample (5 %) was identified to be cognitively disordered (Table 1).

The other included studies focused on diet variety and quality as outcomes. Mental health and intellectual activity, respectively, were identified as neither a predictor of diet variety in a cross-sectional study[34] nor a predictor of a decline in diet variety across 8 years of follow-up[59]. Two studies that were based on the same data set showed no cross-sectional association in the multiple regression between cognitive status assessed by the 3MS (Modified Mini-Mental State) examination and diet quality[58,62]. However, analysis of the longitudinal data identified cognitive status as negative predictor for change in diet quality in men but not in women[62]. The gender difference was confirmed by the cross-sectional study of Keller *et al.* that reported an association between self-reported cognitive function and mean adequacy ratio, as an indicator of diet quality, only in men[45].

Physical function

Nine studies examined the association between physical function and dietary intake (Tables 1 and 2)[34,45,58–62,66,67].

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Table 2 Definition of determinants and outcomes and main results of the studies included in the present systematic literature review on functional determinants of dietary intake in community-dwelling older adults

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Chemosensory function			
Duffy *et al.* (1995)[33]	Olfactory dysfunction: • Standard olfactory dysfunction test on odour thresholds and odour identification	Food intakes, intakes of macro-, micronutrients and energy: • National Cancer Institute FFQ • 24 h food record	Simple correlations: Odour perception was associated with consumption of low-fat milk products ($r=0.24$) and low-fat sweets ($r=-0.23$), as well as with SFA intake ($r=-0.29$), PUFA:SFA ($r=0.24$), cholesterol index ($r=-0.25$), and percentage of energy from total fat ($r=-0.27$) and SFA ($r=-0.32$; all $P<0.05$) Flavour perception was associated with consumption of high-fat desserts ($r=-0.25$; $P<0.05$) No associations were found between both odour and flavour perception and meat, legumes, fruits and vegetables, grain products, beverages, nuts or salty snacks, or with micronutrient intakes or average energy, sugar, cholesterol and protein intakes
Oral function			
Apollonio *et al.* (1997)[35]	Dental status: • Dental examination, classification into 3 groups: naturally adequate dentition, naturally inadequate dentition and denture wearers	Intakes of macro-, micronutrients and energy: • 24 h recall	ANCOVA with education and income as covariates: Mean percentage of vitamin A, B_6, niacin, protein, energy, Fe and folic acid intake was significantly lower in the group with inadequate dental status *v.* the group with adequate dental status and the group with dentures. The group of denture wearers had a significantly lower mean percentage intake of vitamins C, A and folic acid *v.* the group with adequate dental status
Bailey *et al.* (2004)[63]	Oral health: • Questions on mouth/tongue pain, chewing problems, swallowing problems, classification into 2 groups: persistent oral health problem at baseline and follow-up and never reported oral health problems	Intakes of macro-, micronutrients and fibre: • Five 24 h recalls • Healthy Eating Index (HEI)	GLM controlled for age, tobacco use, alcohol use, sex and energy intake: Macronutrient intake did not differ between groups. The group with persistent oral health problems had lower intakes of dietary fibre and vitamin A as well as a lower HEI score, and more often did not meet the EAR for vitamins B_6 and C, *v.* the group without problems
Fontijn-Tekamp *et al.* (1996)[41]	Dental status: • Questionnaire on dentition (edentulous with prosthesis, edentulous with complete dentures, natural teeth, mixture of different types of dentition), chewing difficulties, dentist visits during the last 6 months	Intakes of macro-, micronutrients and fibre: • 3 d estimated dietary record • Food checklist on usual food intake in the past month	ANOVA with town, sex and dentition as factors: Differences between types of dentition were found for intake of carbohydrates ($P<0.05$) and vitamin B_6 ($P<0.01$), with lowest intakes in the edentulous group
Han and Kim (2016)[36]	Dental status: • Oral examination, categorization into denture wearers and non-wearers	Intakes of micronutrients: • 24 h recalls	GLM/complex sample cross-tabs/logistic regression all adjusted for gender, age, income, education, welfare receipt and total energy intake: Compared with denture wearers, edentulous persons without dentures had lower mean intakes of K, niacin and vitamin C. The percentage of inadequate Fe and thiamin intake was higher among participants without dentures than among participants with dentures. In participants without dentures the risk of undernourishment (<75 % of EAR combined with Ca, Fe, vitamin A and riboflavin intake below the respective EAR) was 1·89 (95 % CI 1·01, 3·51) times higher than that of denture wearers
Inomata *et al.* (2014)[46]	Number of remaining teeth/occlusal force: • Oral examination, sum of all occlusal contact sites in the intercuspal position including all regions of the dental arch assessed with pressure-sensitive sheets and analysed by an image scanner	Intakes of micronutrients and fibre: • Brief-type self-administered diet history questionnaire	Linear regression adjusted for gender, educational level, financial status, family structure, area of residence and number of teeth: Decline of occlusal force was associated with lower intakes of vegetables, vitamins A, C and B_6, folate, and fibre (P for trend <0.05) Number of teeth was significantly associated only with Ca and Zn intakes, controlling for occlusal force

https://doi.org/10.1017/S1368980017004244 Published online by Cambridge University Press

Table 2 *Continued*

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Iwasaki *et al.* (2014)[42]	Dental status: • Dental examination on number of posterior occluding pairs (natural, restored or fixed prosthetic post-canine teeth) • Questionnaire on use and fit of dentures • Categorization: good dentition, well-fitting dentures, ill-fitting dentures, compromised dentition	Food intakes, intakes of macro-, micronutrients and fibre: • Brief-type self-administered diet history questionnaire	GLM adjusted for sex, income, education, smoking, alcohol use, BMI and energy intake: The ill-fitting denture group had lower intakes of protein, *n*-3 PUFA, K, Ca, vitamins D, E, B_6 and B_{12} than the good dentition group (all $P<0·05$). The compromised dentition group had lower intakes of protein, *n*-3 PUFA, K, Ca, vitamins A, D, E and B_6, folate and fibre than the good dentition group (all $P<0·05$). Regarding nutrient deficiencies, no differences between the good dentition group and the other groups were found in the adjusted models Intakes of vegetables, fish and shellfish by the ill-fitting denture group or compromised dentition group were significantly lower than those by the good dentition group (all $P<0·05$)
Iwasaki *et al.* (2016)[40]	Dental status: • Dental examination, impaired dentition: functional teeth units ≤5	Food intakes, intakes of macro-, micronutrients, fibre and energy: • Brief-type self-administered diet history questionnaire	Multivariable regression analysis adjusted for sex, income, education, smoking, alcohol use, BMI, ADL and co-morbidities: Declines in intakes of vegetables and meat, as well as in the nutrients protein, Na, K, Ca, vitamins A and E and fibre during follow-up were higher in the impaired dentition group *v.* the non-impaired group (all $P<0·05$)
Kim *et al.* (2007)[47]	Number of teeth: • Tooth count	Food intake: • Frequency of any consumption of meat, fish and fruit during a normal week (‘regular intake’ defined as consumption on at least 4 d/week)	Comparison of group percentages (unadjusted): In the group who did not use dentures, reduced tooth count was associated with a lower regular fish ($P=0·037$) and fruit intake ($P=0·014$)
Kimura *et al.* (2013)[53]	Chewing ability: • Gum changing colour depending on chewing performance, categorization on a 5-point scale (very poor–very good)	Food diversity: • 11-item Food Diversity Score Kyoto (0–11 points, higher score indicates greater food diversity), focusing on consumption of grains, meat, fish and shellfish, eggs, milk, beans and soyabean products, potatoes, vegetables, seaweed, nuts and fruits	Student’s *t* test: Participants with low chewing ability had lower food diversity ($P<0·001$), and less frequent intakes of beans ($P=0·006$), vegetables ($P=0·005$), seaweed ($P<0·001$) and nuts ($P=0·002$), than participants with high chewing ability
Kwon *et al.* (2017)[56]	Chewing difficulties: • Questionnaire	Food intakes, intakes of macro-, micronutrients and energy: • 24 h recall	Complex sample linear models adjusted for age, sex and energy intake: Intakes of vegetables and fruits, Na and vitamin C were lower in the group with chewing difficulties *v.* the normal group (all $P<0·05$). The group with chewing difficulties reached less often the reference values for energy, vitamin C, riboflavin, niacin, Ca and K than the normal group (all $P<0·05$)
Lee *et al.* (2004)[37]	Edentulism: • Self-reports on any remaining natural teeth, wearing dentures and having chewing pain	Intakes of energy, macro-, micronutrients, and fibre; food consumption patterns: • Modified Block 98 FFQ	Linear regressions adjusted for age, race, sex, income, education, study site, living alone, having chewing pain, self-reported health status (and energy): Edentate elderly had lower intakes of dietary fibre, vitamin C, Ca and Mg, and lower percentages of energy from protein and sweets and desserts, than dentate elderly (all $P<0·05$) Edentate elderly consumed fewer foods from fruit and fruit juice groups, fats, oils and sweets groups and hard-to-chew group than dentate elderly (all $P<0·05$)
Liedberg *et al.* (2004)[51]	Dental status: • Dental clinical survey	Intakes of macro-, micronutrients and energy: • Diet history interview	Wilcoxon non-parametric test: No differences in energy and nutrient intakes were found between the groups with fixed and removable dentures

https://doi.org/10.1017/S1368980017004244 Published online by Cambridge University Press

Table 2 *Continued*

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Liedberg *et al.* (2007)[50]	Dental status: • Dental examination: number of teeth, denture wearing, contacts between maxillary and mandibular teeth Masticatory function: • Bolus mixing and bolus-shaping ability by coloured chewing gums, number of chewing strikes to first swallow of an almond • Self-reported chewing ability	Intakes of macro- and micronutrients: • Dietary interview; inadequate dietary intake defined as daily intake of < 0·7 g protein/kg BW, Ca < 400 mg, Fe < 10 mg, vitamin A < 400 μg retinol, thiamin < 1 mg, riboflavin < 14 μg/kg BW, vitamin C < 20 mg	χ^2 test/Student's *t* test: No differences in the frequency of natural teeth, removable dentures, number of occlusal tooth contacts, masticatory function and self-reported chewing ability between groups with adequate and inadequate intake were found
Lin *et al.* (2010)[54]	Chewing ability: • Questions on satisfaction with dentures, chewing difficulty and discomfort during mastication	Food intake: • 24 h recall	Fischer's exact test: RDA for vegetables were less often fulfilled by participants feeling discomfort during mastication *v.* those not feeling discomfort ($P = 0·015$) Participants with chewing difficulties fulfilled less often the RDA of 5 different food groups (grains, milk products, meat and beans, vegetables and fruits) *v.* those without chewing difficulties ($P = 0·0186$)
Marcenes *et al.* (2003)[38]	Dental status: • Dental examination: distribution of natural teeth, total number of occluding natural pairs of teeth, spaces, partial dentures and condition of teeth • 50 questions on social, socio-dental and behavioural variables including the effect of dentition	Intakes of macro-, micronutrients and fibre: • 4 d weighed food diary	Linear regression adjusted for age, sex, social class, region of residence and partial denture wearing: Edentulous individuals had lower intakes of fibre, intrinsic and milk sugars ($P < 0·001$), protein, Ca, riboflavin, niacin, pantothenic acid, vitamin C ($P < 0·01$), non-haem Fe, thiamin and vitamin E *v.* dentate persons ($P < 0·05$) Among people with natural teeth, those with more teeth had greater mean daily intakes of fibre, total carbohydrates, intrinsic and milk sugars ($P < 0·001$), energy, Ca, non-haem Fe ($P < 0·01$), protein, fat and vitamin C ($P < 0·05$)
Marshall *et al.* (2002)[48]	Oral health: • Oral examination: number of natural teeth and functional teeth, presence of complete/incomplete natural dentition and of coronal and root caries, use of partial and/or complete dentures	Intakes of macro-, micronutrients, diet quality: • 3 d dietary record • Diet quality score	Simple correlations: • Total number of teeth as well as number of functional teeth correlated with mean daily intakes of protein ($r = 0·139$), vitamin C ($r = 0·140$), Ca ($r = 0·162$) and Zn ($r = 0·177$), as well as with diet quality score ($r = 0·161$; all $P < 0·05$) • Complete or incomplete natural dentition as well as caries was not associated with mean nutrient intakes • Coronal caries and total caries were associated only with Ca intake ($r = 0·165$, $r = 0·138$, $P < 0·05$) Kruskal–Wallis test: • Participants with retention or stability problems with the mandibular denture had lower intakes of pantothenic acid, thiamin, riboflavin, vitamin D, Ca, Fe, Mg and P as well as a lower dietary quality score (all $P < 0·05$) *v.* participants without problems • Retention or stability problems were associated with inadequate nutrient intakes of vitamin B_6, Ca, Mg and P (all $P < 0·05$) • Nutrient intakes and dietary quality did not differ between types of dentures, or having complete natural dentition and incomplete natural dentition
Nordström (1990)[43]	Oral status: • Standardized interview • Dental examination: evaluating conditions in the jaw muscles and the temporo-mandibular joints according to Krogh-Poulson, anamnestical and clinical mandibular dysfunction indices according to Helkimo and dental status according to Eichner Index	Intakes of macro-, micronutrients and energy: • Diet history interview	Stepwise regression: Chewing problems were a negative predictor of the principal component (energy, protein, fat, carbohydrates, all minerals, thiamin, riboflavin, vitamins B_6 and D). Upper denture status/Eichner Index as well as anamnestical mandibular dysfunction were negative predictors of the principal component (alcohol and vitamin D). Upper denture status/Eichner Index was a negative predictor for vitamin C intake. Chewing problems were associated with a more frequent intake of energy, protein, fat and thiamin below the RDA

Table 2 *Continued*

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Österberg and Steen (1982)[44]	Dentate status: • Dental examination using Eichner Index	Food intakes, intakes of macro-, micronutrients and energy: • Diet history interview	Pitman's test considering school and professional education, marital status and income: Males: Eichner Index was associated with protein, thiamin, and an insufficient intake of one or more nutrients Females: No association between Eichner Index and dietary intake was found
Österberg *et al.* (2002)[39]	Dental status: • Dental examination: location and number of remaining teeth, kinds of dental treatment, estimation of antagonistic occlusal contact according to the Eichner Index and use of prostheses Masticatory ability: • Bite force • Questionnaire for self-reported masticatory ability (9 items)	Intakes of micronutrients and fibre: • Dietary interview, diet history (last 3 months) • Nutrient density index (range 0–7): lowest quintile of nutrient intake/1000 kcal (4187 kJ) for vitamin D, vitamin C, thiamin, riboflavin, Ca, Fe and fibre	Bivariate correlations (coefficients were not reported): Deteriorated dental status was associated with higher intakes of porridge, pasta and sausage, and with lower intake of vegetables (all $P < 0{\cdot}05$). Regarding nutrient intakes, deteriorated dental status was associated with lower intake of vitamin D in women and higher carbohydrate intake in men (all $P < 0{\cdot}05$) Bite force was positively correlated with protein intake, with fibre intake in women, and with vegetable intake in men (all $P < 0{\cdot}05$)
Sheiham *et al.* (2001)[31,32]	Dental status: • Dental examination: on distribution of natural teeth, number of occluding natural pairs of teeth, spaces and partial dentures, condition of teeth	Intakes of macro-, micronutrients, fibre and energy: • 4 d weighed record	Multivariate logistic regression adjusted for age, sex, social class and region of residence: Intakes of protein, intrinsic and milk sugars, fibre, Ca, non-haem Fe, niacin, pantothenic acid, thiamin, riboflavin, vitamins C and E (all $P < 0{\cdot}05$) were higher in dentate *v.* edentate older adults. Comparing groups with natural teeth (1–10 *v.* 11–20 *v.* 21 +), those with more teeth had higher intakes of energy, protein, fat, carbohydrates, intrinsic and milk sugars, fibre, Ca, non-haem Fe, pantothenic acid, vitamins C and E (all $P < 0{\cdot}05$)
Tsai and Chang (2011)[52]	Dental status: • Question on wearing dentures (fixed, removable, none) • Rating of masticatory function by 5-point Likert scale	Food intake: • Interview on consumption of major food categories	χ^2 test: No denture wearers consumed less often dairy products and fruits *v.* fixed and removable denture wearers (all $P < 0{\cdot}05$) Fixed denture wearers consumed more often vegetables *v.* removable and no denture wearers (all $P < 0{\cdot}05$) Removable denture wearers consumed less often cereals *v.* fixed and no denture wearers (all $P < 0{\cdot}05$) No difference in the consumption of meat, fish, seafoods, eggs and legumes were found between fixed, removable and no denture wearers
Woo *et al.* (1994)[57]	Chewing difficulties: Not reported	Food intake: • Frequency of consumption per week of certain foods which might be more difficult to chew and therefore could be avoided by those with chewing difficulties	χ^2 test: No differences were found in the frequency of consuming vegetables, fruits or meat between groups with and without chewing difficulties
Yoshida *et al.* (2011)[55]	Dental status: • Oral examination: classification according to Eichner in retained contact group (who had retained molar occlusion in at least one molar region with natural teeth) *v.* lost contact group (individuals who had no occlusal contact with natural dentition in the molar region)	Food intakes and intakes of micronutrients and fibre: • Brief self-administered diet history questionnaire • Interviews by a dietitian	ANOVA adjusted for age and sex: The lost contact group consumed fewer vegetables ($P = 0{\cdot}048$) and more confectionery ($P = 0{\cdot}005$) and had lower intakes of fibre, carotene, vitamin K, thiamin, vitamins B_6 and C *v.* the retained contact group. Energy and macronutrient intakes did not differ between groups

Table 2 *Continued*

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Yoshihara *et al.* (2005)[49]	Number of teeth: • Dental examination: on number of teeth (0–19 *v.* 20 +), status of teeth and use of removable denture	Food intakes, intakes of macro-, micronutrients and energy: • 3 d weighed record	Multiple linear regression adjusted for gender, smoking and educational level: Number of teeth was positively associated total and animal protein intakes ($P<0·001$), Na, K, P, Fe ($P<0·01$) and Mg ($P<0·05$) intakes, vitamin B_6, niacin ($P<0·001$), thiamin, folic acid, pantothenic acid, riboflavin ($P<0·01$), vitamins D and E ($P<0·05$) intakes, and cholesterol intake ($P<0·05$) Student's *t* test comparing groups with 0–19 teeth *v.* 20 + teeth: Participants with 0–19 teeth had lower intakes of total ($P<0·01$) and animal protein ($P<0·05$), Na ($P<0·05$), thiamin, niacin ($P<0·001$), vitamin B_6 ($P<0·01$), vitamin D and pantothenic acid ($P<0·05$), as well as lower vegetable and fish ($P<0·05$) intakes, than participants with 20 + teeth
Cognitive function			
de Rouvray *et al.* (2014)[65]	Dementia: • CSI-D • 5-Word Test • Neuropsychological examination to confirm presence/absence of dementia	Food intake: • FFQ	χ^2 test: Participants with dementia had lower intakes of fruits ($P=0·008$) and meat or fish ($P=0·02$) *v.* those without dementia
Shatenstein *et al.* (2006)[64]	Alzheimer dementia: • DSM-IV criteria	Intakes of macro-, micronutrients and fibre: • 2 non-consecutive days of food records or 24 h diet recalls for current diet once per month	*t* test: Baseline: Intakes of energy, macronutrients, Ca, Fe, Zn, vitamin K, vitamin A, dietary fibre, *n*-3 and *n*-6 fatty acids were significantly higher in controls than in cases (with dementia) Controls had higher intakes of many nutrients at all time points with exception of folate
Physical function			
Sarti *et al.* (2013)[66]	Physical performance: • SPPB Strength: • Handgrip strength • Knee extensor isokinetic and isotonic strength (Dynatronic 100 ergometer)	Intakes of macronutrients and energy: • Estimated 3 d record • FFQ (previous months)	Pearson's linear correlations: Changes in walking speed correlated with changes in energy intake ($r=0·34$, $P<0·001$) across 3 years. The association remained significant after adjusting for changes in protein intake, strength and PTH No other associations between functional measures and dietary intake were found
Bianchetti *et al.* (1990)[67]	Functional status: • IADL	Intakes of macro-, micronutrients: • 24 h recall	χ^2 test: Males: Percentage of those with vitamin A and niacin intake below two-thirds of the RDA was higher in the group with functional limitations *v.* the group without functional limitations Females: Percentage of those with protein, vitamin C, B_{12}, A, niacin and Fe intake below two-thirds of the RDA was higher in the group with functional limitations *v.* the group without functional limitations
Multiple functional domains			
Dean *et al.* (2009)[34]	Dental health: • Question (5 point-scale, strongly disagree–strongly agree) Mobility: • Question (see above) Taste and smell ability: • Question (see above) Mental health: • MCS8, SF-8	Diet variety: • Weekly food variety score according to the biological/botanical origins of the food (15 points, adequate; 30 points, excellent)	Multiple hierarchical regression: Perceived dental health, mobility as well as taste and smell ability were not identified as predictors of diet variety. The association between mental health and diet variety was lost when adding resources and nutrition-related goals to the statistical model
Holmes and Roberts (2011)[61]	Oral health: • Face-to-face interview (experiencing difficulty chewing) Disability: • Face-to-face interview (has longstanding illness or disability that limits shopping/food preparation)	Diet quality: • 24 h recalls on 4 non-consecutive days • Diet quality index (max. 9 points)	Multivariate stepwise logistic regression analysis: Men with chewing difficulties were less often in the group with a high diet quality (6–8 points) than those without chewing difficulties (OR = 0·40; 95 % CI 0·13, 0·99). No association was found in women. Disability was not associated with diet quality in both sexes

Table 2 *Continued*

Reference	Determinant (name/method)	Outcome (name/method)	Statistical approach and main results
Keller *et al.* (1997)[45]	Physical function: • Self-reported walking difficulties • Self-reported difficulties with basic self-care (IADL, ADL) Oral function: • Self-reported chewing difficulties • Self-reported denture use or having no teeth Cognitive function: • Self-reported ability to think	Diet quality and energy intake: • FFQ (84 items) • MAR (range = 0–1, 1 indicates the likelihood that intakes of all nutrients included meet or exceed the requirements of each individual) • Diet score (max. 20 points based on the number of portions consumed each day from each of four food groups)	Multiple linear regression: Men: Chewing difficulties were associated with a poor diet score. Having their own teeth rather than dentures was associated with poorer MAR and lower energy intake. IADL dependence was associated with higher energy intake. Think clearly was positively associated with MAR Women: Chewing difficulties were associated with a poor diet score. Walking difficulties were associated with better diet score, MAR and higher energy intake. IADL dependence was associated with poorer diet score
Kwon *et al.* (2006)[59]	Self-perceived chewing ability: • Good ability *v.* deterioration of chewing ability *v.* improvement of chewing ability Instrumental self-maintenance: • TMIG Index of competence Intellectual activity: • TMIG Index of competence	Diet variety: • FFQ with 10 food groups commonly used in Japan (1 week) • Diet variety score (max. 10 points; 1 point = have eaten every day, 0 points = not eaten for 1 day or more)	Multiple logistic regression adjusted for age, gender, instrumental self-maintenance score, intellectual activity score, social role score and diet variety score at baseline: Predictors for dietary variety decline during 8-year follow-up: deterioration of chewing ability (OR = 3·31; 95 % CI 1·36, 8·08), but not changes in self-maintenance and intellectual activity
Posner *et al.* (1994)[60]	Cognitive status: • Normal cognitive status *v.* mild confusion based on interviewer judgement of 5 specific behaviours Physical function: • MOS SF-36 instrument (0–12 points) Dental state: • Examination: dentures, no teeth or root tips only *v.* at least 1 tooth Dental decay: • No decayed root surfaces and ≤2 decayed coronal surfaces *v.* 1 + decayed root surfaces or 3 + decayed coronal surfaces Difficulty chewing: • Question: yes *v.* no	Intakes of micronutrients: • 24 h recall Nutritional inadequacy: • Sum of nutrients (vitamin A, vitamin C, thiamin, Ca, protein) that were consumed 75 % of the RDA or below	Multiple regression adjusted for age and gender, moreover all other assessed variables were entered in the model: • Dental decay (0·346), dentate status (–0·436) were associated with the nutrient inadequacy score Logistic regression with age, gender, living situation and tobacco use as additional variables: • Predictors for low vitamin A intake: dental decay (0·623) and dentate status (–0·426) • Predictors for low vitamin C intake: dental decay (0·478) • Predictors for low thiamin intake: dentate status (–0·610) and dental decay (0·506)
Shatenstein *et al.* (2013)[58]	Cognitive status: • 3MS Perceived dental status/chewing problems: • Oral health impact profile questionnaire Functional status: • SMAF • Functional capacity index • Rapid walking speed • One-leg stance test	Diet quality: • 3 non-consecutive 24 h recalls (face-to-face or telephone interviews) • C-HEI (max. 100 points, higher scores indicating better diet quality)	ANOVA: • Men and women in the highest quartile of C-HEI showed better cognitive and functional status (walking speed, one-leg stance) *v.* the other quartiles ($P < 0·05$) • Women: higher dietary quality was associated with less chewing problems ($P < 0·05$) Predictors of global diet quality backward stepwise multiple regression: • Men: wearing dentures ($\beta = -2·31$, $P = 0·01$) • Women: chewing problems ($\beta = -0·48$, $P = 0·03$)
Shatenstein *et al.* (2016)[62]	Cognitive status: • 3MS Perceived dental status/chewing problems: • Oral health impact profile questionnaire Functional status: • SMAF • Rapid/normal walking speed • One-leg stance test	Diet quality: • 3 non-consecutive 24 h recalls (face-to-face or telephone interviews) • C-HEI (max. 100 points, higher scores indicating better diet quality)	Spearman's rank correlation: • At baseline among men, cognitive status, functional autonomy, one-leg stance and rapid walking speed were associated with diet quality; among women, only normal walking speed Stepwise backward regression analysis: • Among men a negative predictor of change in diet quality was cognitive status ($\beta = -0·535$, $P < 0·003$); in women, no functional determinant was predictive for change in diet quality

CSI-D, Community Screening Interview for Dementia; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders, 4th ed., SPPB, Short Physical Performance Battery; IADL, instrumental activities of daily living; MCS8, Mental Component Score; SF-8, Short-Form 8-Item Health Survey; ADL, activities of daily living; TMIG, Tokyo Metropolitan Institute of Gerontology Index; MOS SF-36, Medical Outcome Study Short Form Health Survey; 3MS, Modified Mini-Mental State examination; SMAF, Système de mesure de l'autonomie functionnelle; BW, body weight; MAR, mean adequacy ratio; C-HEI, Canadian Healthy Eating Index; GLM, general linear model; EAR, Estimated Average Requirement; PTH, parathyroid hormone.

Three studies used objective measures comprising handgrip strength, Short Physical Performance Battery, gait speed or standing balance to describe physical function[58,62,66]. One of these, a small longitudinal study in older women, focused on energy and macronutrient intakes as outcomes and found an association between the change in walking speed and the change in energy intake across 3 years of follow-up[66]. No other functional measure was identified as a determinant of energy or macronutrient intake. In two other studies higher walking speed and better standing balance were not identified as predictors of diet quality at baseline (multiple regression) and of change in diet quality during 3 years of follow-up[58,62]. Of the six studies using questionnaire-based measures to evaluate functional status, four showed no association between physical functional factors and the outcomes diet quality, diet variety and nutrient intakes[34,59–61]. In a cross-sectional study comparing subjects with and without functional limitations, differences in reaching the RDA for different nutrients were observed[67]. Keller *et al.* reported higher energy intake in men with IADL (instrumental activities of daily living) dependency and poorer diet quality in women with IADL dependency compared with the reference groups[45].

Discussion

The present systematic literature review compiled the knowledge on functional determinants of dietary intake in community-dwelling adults aged 65 years or older.

One important finding is that research on determinants is scarce. By definition a factor is a determinant of a specific behaviour if a variation in this factor is systematically followed by variation in the behaviour[68]. As no intervention studies were identified and most studies dealing with this topic had a cross-sectional design, it is only possible to speak about correlates, predictors or factors of dietary intake. Moreover, in some studies investigation of the relationship between functional factors and dietary intake was only a secondary aim[47,52,65]. Consequently, the results were just presented in a descriptive manner based on bivariate correlational approaches or simple comparisons of means, which negatively affected the quality assessment. Multifactorial analyses of various independent variables and sufficiently adjusted statistical models were often missing. Altogether, it is not possible to make any statement on the extent to which the single factors affect dietary intake.

The number of publications investigating the different functional domains of chemosensory, oral, cognitive and physical function varied. While oral factors were extensively studied, evidence in other fields is poor and the findings were partly inconsistent.

Dietary intake

In the current review the outcome 'dietary intake' covers a broad range of different aspects: intakes of certain food groups, macronutrients, micronutrients and fibre, diet quality and diet variety. Regarding the definition of the outcome as well as its assessment, heterogeneity between studies was found. Those studies looking at food and nutrient intakes mostly did not focus on specific food groups or nutrients but reported associations between the determinants and a broad range of dietary aspects, leading to the problem of significance by multiple testing. The studies varied with respect to the tools used to assess current intake (e.g. 24 h recalls, estimated dietary records, weighing protocols), habitual intake (e.g. FFQ, diet history) and the respective reference periods (e.g. few days, one week, three months, one year). Eleven studies showed shortcomings within the quality assessment regarding the outcome measures used. A validation of the tools was not always given, especially for the used food lists. Moreover, some studies used just one 24 h recall, which is presumably insufficient to display dietary intake properly and to consider differences between weekdays and weekend days. As studies from four different continents were considered, the different eating cultures may also partly explain differences in results.

Oral function

A high number of studies reported oral function as a correlate of dietary intake in community-dwelling older adults. Different surrogates of oral function (i.e. dental status, number of teeth, bite force and chewing problems) were associated with food as well as nutrient or fibre intake[31,32,35–40,42–49,52–56,59,60,63]. Against expectations, a relationship between oral impairment and a reduced intake of meat was only infrequently described[37,40,54]. Moreover, it should be noticed that the detected differences between groups with and without problems in oral function are not necessarily clinically meaningful, as a lower intake is not equal to insufficient intake. Nine of the included studies specifically addressed this issue[35,42–45,48,50,60,63], with seven studies reporting more often an intake of certain nutrients not meeting the respective recommendations in the groups with oral problems compared with the groups without oral problems[35,43–45,48,60,63]. The nutrients for which the intake was inadequate differed between studies. Most often vitamin C and Ca intakes were identified. The insufficient vitamin C intake could be linked to a lower consumption of fruits and vegetables which was often reported in participants with oral problems[37,42,54,55]. The association between oral problems and low protein intake[31,32,35,38,39,43,48,49] needs to be discussed independently of the respective reference values, as current recommendations on daily protein intake are considered too low for older adults to preserve the age-related loss of muscle mass[69]. As chewing ability is related to sarcopenia[70], protein intake in older adults with oral problems should receive special attention.

Our results are in line with those of another systematic review focusing specifically on the association between mastication and food and nutrient intakes in older people[29]. The systematic review differs from our work regarding search terms and younger inclusion age (≥50 years). Tada and Miura also considered some intervention studies, not matching our inclusion criteria, which could not show an effect of a prosthetic treatment on food intake[29], indicating that, under these conditions, oral function is only a small contributor to the complex dietary behaviour of older people.

In the studies included in our review, a huge variety of different oral factors was examined. Unfortunately results were often presented for single factors only and without adjustment, while multifactorial approaches entering several oral factors simultaneously or stepwise in the respective statistical models were scarce[37,58–60,62]. Consequently, it is difficult to conclude on the extent to which the single factors influence dietary intake and how they are interrelated. Moreover, due to the different assessment methods, comparability is limited.

When speaking about existing evidence that oral function is a factor of dietary intake in community-dwelling older adults, we have to exclude swallowing function as our search identified only one study investigating swallowing function[63] and that study did not present the results on swallowing function separately but solely differentiated between persistent oral health problems and no oral health problems[63]. About 15 % of community-dwelling older adults are affected by dysphagia[71]. Depending on the severity, persons concerned are forced to eat soft and texture-modified foods, which increases the risk of inadequate intakes of energy and nutrients[24]. Further research is needed in this field.

Chemosensory function

As only two studies were identified examining the relationship between chemosensory function and dietary intake[33,34], using different methodological approaches and showing controversial results, no statement on the role of chemosensory function on older people's dietary intake can be derived. Chemosensory impairment is described as a common problem in the older population that often remains unrecognized by the older people due to gradual changes in chemosensory function[23,72–74]. Moreover, chemosensory function is discussed as a factor in the complex pathophysiology of anorexia of ageing[75–77]. Consequently, the impact of chemosensory function on food choices and dietary intake needs further clarification. This should also include the testing of interactions between taste and smell perceptions, and the examination of potential compensatory mechanisms to overcome chemosensory dysfunction. In one study mentioned above, eating foods with a creamy mouth feeling was described as such a strategy[33].

Cognitive function

The eight studies investigating cognitive function in relation to dietary intake showed inconsistent results. Those considering dementia as a disease reported lower intakes in those who were affected[64,65]. Studies referring to cognitive impairment revealed no association with diet variety[34,59] or that diet quality was reduced only in men with cognitive impairment but not in women[45,62]. Generally, evidence regarding this topic is low and no clear statement can be derived that cognitive function is a determinant of dietary intake in community-dwelling older adults. As dementia and cognitive impairment are well known as risk factors for malnutrition in the older population[78,79], the assumption that these factors are also linked to dietary intake is obvious. Dietary intake can be seen as a mediator in the origin of malnutrition. However, a considerable number of studies were excluded from the current review as they looked at the topic the other way around, examining the preventive potential of certain nutrients or specific dietary patterns like the Mediterranean diet on cognitive function[5,6,80–82].

Physical function

The studies investigating physical function as a factor of dietary intake mostly showed no or only slight associations. However, the limited evidence does not allow any conclusions. From the theoretical point of view physical limitations may lead to an unbalanced diet via impeding shopping, cooking, opening packages, cutting foods and eating. A sound foundation of this hypothesis by research is missing. As in most studies participants were in good general health, functional limitations might be not pronounced enough to affect the aforementioned tasks. Moreover, it would be useful to assess in addition to functional limitations also social support, as this aspect is important to cope with the problem. Regarding the methods to assess physical function, the questionnaires used might often be inappropriate to detect participants with beginning functional decline or to discriminate between groups with and without physical limitations. Concerning community-dwelling older people, questionnaire-based instruments focusing on instrumental activities like cooking and shopping, as addressed in the studies of Bianchetti *et al.*[67] and Keller *et al.*[45], might be more suitable than questionnaires on basic activities of daily living. Even though the studies by Shatenstein *et al.*[58,62] failed to identify physical functional factors as determinants of diet quality, such approaches considering both objective and subjective functional measures might be useful to cover diverse functional domains with different levels of complexity.

Multiple functional domains

Besides several functional factors, some of the studies also considered psychosocial determinants[34,45,58–62]. Although these studies are difficult to compare concerning the independent factors and the outcome variables, they have the advantage that the influence of multiple factors is displayed, reflecting the complexity of dietary behaviour and the interplay of individual factors of different determinant domains. Very recently within the DEDIPAC project an interdisciplinary framework of determinants on nutrition and eating across the lifespan was developed, displaying (besides multiple determinant levels) also modifiability and the research priority of each determinant[21]. This framework can guide future research on determinants of dietary behaviour.

Limitations

A selection bias cannot be excluded. First, it is possible that not all studies dealing with the topic are indexed in the searched databases. Second, the search was based on a list of terms describing the potential determinants of the different domains. We tried to be as complete as possible; however, it cannot be excluded that by adding some other terms additional relevant papers would have been identified. Third, restrictive inclusion and exclusion criteria were used. As our work should focus on older adults, we only included studies based on our inclusion criterion of age ≥65 years. Considering also studies with a mean age of ≥65 years but a lower inclusion age for participants would have extended the results. On the other hand, this approach could obscure the intended characterization of determinants of dietary intake in the old age group, as people aged between 50 and 65 years are normally still working, which could confound the dietary behaviour. Moreover, most of the excluded studies using age cut-off between 50 and 60 years did not meet at least one inclusion criterion irrespective of the age aspect. Although we focused only on studies in English, the language bias is presumably low as only seven studies were excluded due to the language criterion and is likely that they did not meet other inclusion criteria. The same is true for the exclusion of conference abstracts. A last point which should be addressed as a limitation is publication bias, as studies with negative results are less often published.

Conclusion

The current systematic literature review presented a considerable number of studies reporting associations of the oral factors dental status and chewing ability with dietary intake in community-dwelling older adults. However, as most of the studies had a cross-sectional design and many presented non-adjusted data, no causal relationship could be derived. With regard to the other determinants, chemosensory, cognitive and physical function, data were either inconsistent or insufficient to conclude on any meaningful relationship. Future prospective studies specifically designed to measure determinants of dietary behaviour are needed. Attempts to align research by using the same standardized and validated tools should be further fostered to increase comparability of study results and to simplify the transmission of study results into effective public health strategies.

Acknowledgements

Acknowledgements: The preparation of this paper was supported by the DEterminants of DIet and Physical ACtivity (DEDIPAC) knowledge hub. This work is supported by the Joint Programming Initiative 'Healthy Diet for a Healthy Life'. *Financial support:* The funding agencies supporting this work are as follows (in alphabetical order of participating Member State). France: Institut National de la Recherche Agronomique (INRA). Germany: Federal Ministry of Education and Research (grant number 01EA1382). Italy: Ministry of Education, University and Research; Ministry of Agricultural, Food and Forestry Policies (grant number DEDIPAC-IRILD, D.M. 14474/7303/13, n.7953). The Netherlands: The Netherlands Organisation for Health Research and Development (ZonMw; grant number 200600003). Poland: The National Centre for Research and Development (grant number DZP/2/JPI HDHL DEDIPAC KH/2014). The funders had no role in the design, analysis or writing of this article. *Conflict of interest:* E.K., E.P., S.M., L.M.D., C.S.-R., A.Su., K.W.-T., W.P., D.Ł., A.Sa., F.S., A.P., E.M., D.C. and J.B. report that they have no potential conflict of interest. C.F. reports receiving fees for conferences from Danone Research and Nutricia. D.V. reports grants from Karl-Düsterberg Stiftung, outside the submitted work; and is a member of the scientific advisory board of Apetito. *Authorship:* E.K. planned the review, conducted the search, study selection, data extraction and evaluation, and drafted the paper. E.P., S.M., L.M.D., C.S.-R., C.F., A.Sa., D.C., F.S., E.M., A.P., A.Su., K.W.-T., W.P. and D.Ł. contributed to the planning of the review, conducted the study selection, data extraction and evaluation, and revised the paper. J.B. contributed to the planning of the review and evaluation of the data and revised the paper. D.V. planned the review, contributed to the study selection, conducted the data evaluation and revised the manuscript. *Ethics of human subject participation:* Not applicable.

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1368980017004244

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