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Original Article

Association between occlusal supports and nutritional status in older adults: A systematic review

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KEYWORDS
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Systematic review

Abstract *Background/purpose:* Impaired masticatory performance results in nutritional deficiencies in older adults. This systematic review aims to investigate the following clinical question (CQ): Do occlusal supports impact nutritional intake or nutritional status in older individuals?
Materials and methods: An extensive systematic literature search was performed to summarize the currently available knowledge to address the CQ. The cohort and intervention studies with participants of ≧60 years old or a mean age of 65 years performed before May 2021 were included. Studies were required to measure the parameters related to occluding tooth pairs/occlusal units and food/nutrient intake and/or nutritional status. Bias risk was assessed using the Risk of Bias Assessment Tool for Nonrandomized Studies.
Results: After an independent screening of 1130 initial records, 24 reports from 22 studies were included. Participants (n = 8684) in the included studies were mainly residents of nursing

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homes or community-dwelling individuals. Following the assessment of bias risk, it is revealed that all studies had methodological weaknesses. Over half of the studies concluded that there was an association between occlusal support and nutritional intake or status. However, it was also revealed that various confounding factors are involved in the association between occlusal support and nutrition.

Conclusion: This systematic review concludes that occlusal support might be associated with nutritional intake or nutritional status in the older population, although there are methodological limitations of each study. The evidence is still insufficient, and more well-designed studies are required.

Introduction

Epidemiological studies suggest that the number of individuals over 60 years old is expected to increase to over 2 billion by 2050, representing 22% of the population.[1] Since the prevalence of cardiovascular disease, obesity, diabetes, and other chronic noncommunicable disease (NCDs) increase with age, the age-related health decline is recognized as a critical social problem worldwide, particularly in developing and transitional economies.[2] It should be emphasized that proper nutrition is essential in an aging society to avoid the progression of NCDs and to maintain a healthy lifestyle. Nutritional factors were recommended for inclusion as a focal point for all health care professionals.[3]

It is fundamental to establish proper dietary habits with appropriate oral care for healthy aging. Individuals with compromised dentition cannot masticate as well as those possessing full dentition.[4] They often compensate by chewing for extended periods and swallowing coarser food particles.[4] Tooth loss and reduced bite force significantly impact food choices.[5] Various studies reveal a relationship between decreased intake of certain nutrients and reduced health. Individuals with compromised dentition have a high risk of malnutrition and subsequent diseases due to poor nutritional status.

Previous systematic reviews mainly focused on the correlation between nutritional status and the number of teeth. However, to date, there is limited evidence demonstrating the effect of occlusal supports on nutritional status. This study aimed to conduct a systematic review investigating the following clinical question (CQ): Do occlusal supports impact nutritional intake/status in older individuals?

Materials and methods

This systematic review presented the focused question: "Is the amount of occluding support associated with nutritional intake/status in older individuals?". A search strategy was applied according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) protocol.[6,7]

Search strategy

Broad criteria were predefined to select articles for inclusion, following the PECO format. An extensive literature search was performed to summarize the currently available knowledge to answer the CQ using PubMed, Cochrane Library, and Web of Science databases for the studies investigating the association between amount of occlusal supports and nutritional intake/status prior to 15th May 2021. The search terms used in PubMed are listed in Table 1. Additional electronic search was performed in other databases with a similar search strategy.

Study selection

Initially, titles and abstracts of all retrieved articles were screened for potentially eligible studies. Full-length articles of the identified studies were examined in detail according to eligibility criteria of this review. Two reviewers (RM and KM) independently performed the screening process. The agreement between them was calculated using kappa statistics. Disagreement between reviewers was resolved by discussion until consensus was reached through further discussion.

The following factors were required for inclusion:

1. Participants $\geqq$60 years old or mean age of cohort $>$65 years old
2. Studies that performed any of the following oral evaluations: occluding pairs of teeth, functional units (FU), functional teeth units (FTU), posterior occluding pairs (POPs), Kennedy classification, and Eichner index.
3. Studies that performed any of the following nutritional evaluations: questionnaire about dietary intake, body mass index (BMI), serum nutritional markers such as albumin, and Mini Nutritional Assessment (MNA) or its short-form (MNA-SF),
4. Studies in which an oral examination was performed by a dental professional. Both observational and interventional studies were screened for eligibility. Only the baseline data of interventional studies that fulfilled the aforementioned criteria were screened.

Exclusion criteria were as follows:

1. Case reports, *in vitro* studies, experimental animal studies, letters to the editor, and systematic or narrative reviews
2. Self-reported oral health outcomes

Table 1 Search keywords using in this systematic review.

PECO component	Search keywords
P-Population	("aged"[MeSH Terms] OR "aged"[All Fields] OR "aging"[MeSH Terms] OR "aging"[All Fields] OR "aged, 80 and over"[MeSH Terms] OR "elder"[All Fields] OR "elderly"[All Fields] OR "geriatric"[All Fields] OR "senior"[All Fields] OR "old age"[All Fields])
	AND
E-Exposure (C-Comparison)	((((("eichner"[All Fields] OR "eichner s"[All Fields]) AND ("classification"[MeSH Terms] OR "classification"[All Fields] OR "classifications"[All Fields] OR "classification"[MeSH Subheading] OR "classification s"[All Fields] OR "classificator"[All Fields] OR "classificators"[All Fields] OR ("abstracting and indexing"[MeSH Terms] OR ("abstracting"[All Fields] AND "indexing"[All Fields]) OR "abstracting and indexing"[All Fields] OR "index"[All Fields] OR "indexed"[All Fields] OR "indexes"[All Fields] OR "indexing"[All Fields] OR "indexation"[All Fields] OR "indexations"[All Fields] OR "indexe"[All Fields] OR "indexer"[All Fields] OR "indexers"[All Fields] OR "indexs"[All Fields]))) NOT eichner[Author]) OR (("kennedy"[All Fields] AND ("classification"[MeSH Terms] OR "classification"[All Fields] OR "classifications"[All Fields] OR "classification"[MeSH Subheading] OR "classification s"[All Fields] OR "classificator"[All Fields] OR "classificators"[All Fields] OR ("abstracting and indexing"[MeSH Terms] OR ("abstracting"[All Fields] AND "indexing"[All Fields]) OR "abstracting and indexing"[All Fields] OR "index"[All Fields] OR "indexed"[All Fields] OR "indexes"[All Fields] OR "indexing"[All Fields] OR "indexation"[All Fields] OR "indexations"[All Fields] OR "indexe"[All Fields] OR "indexer"[All Fields] OR "indexers"[All Fields] OR "indexs"[All Fields]))) NOT kennedy[Author]) OR ("tooth units"[All Fields] OR ("tooth"[All Fields] AND "units"[All Fields]) OR "occlusal pairs"[All Fields] OR ("occlusal"[All Fields] AND "pairs"[All Fields]) OR "occluding pairs"[All Fields] OR ("occluding"[All Fields] AND "pairs"[All Fields]) OR "functional units"[All Fields] OR ("functional"[All Fields] AND "units"[All Fields]) OR "occlusal units"[All Fields] OR ("occlusal"[All Fields] AND "units"[All Fields]) OR "occlusal contacts"[All Fields] OR ("occlusal"[All Fields] AND "contacts"[All Fields]) OR "occlusal support"[All Fields] OR ("occlusal"[All Fields] AND "support"[All Fields]) OR "tooth pairs"[All Fields] OR ("tooth"[All Fields] AND "pairs"[All Fields]))))
	AND
O-outcome	("malnutrition"[MeSH Terms] OR "malnutrition"[All Fields] OR "Nutritional Status"[MeSH Terms] OR ("Nutritional"[All Fields] AND "Status"[All Fields]) OR "Nutritional Status"[All Fields] OR "undernutrition"[All Fields] OR "underfed"[All Fields] OR "body composition"[MeSH Terms] OR ("body"[All Fields] AND "composition"[All Fields]) OR "body composition"[All Fields] OR "thinness"[MeSH Terms] OR "thinness"[All Fields] OR "underweight"[All Fields] OR "weight loss"[MeSH Terms] OR ("weight"[All Fields] AND "loss"[All Fields]) OR "weight loss"[All Fields] OR "energy intake"[MeSH Terms] OR "energy intake"[All Fields] OR ("food"[All Fields] AND "intake"[All Fields]) OR "food intake"[All Fields] OR "anorexia"[MeSH Terms] OR "anorexia"[All Fields] OR "fasting"[MeSH Terms] OR "fasting"[All Fields] OR "hunger"[MeSH Terms] OR "hunger"[All Fields] OR "body mass index"[MeSH Terms] OR "body mass index"[All Fields] OR "cachexia"[MeSH Terms] OR "cachexia"[All Fields] OR "wasting syndrome"[MeSH Terms] OR ("wasting"[All Fields] AND "syndrome"[All Fields]) OR "wasting syndrome"[All Fields])

Data extraction

For eligible studies, the information including authors, journal, publication year, type of study, participants' characteristics (sample size, age, range, and country), follow-up periods, oral evaluations, nutritional evaluations, covariates, and main findings were extracted.

Quality assessment

Two researchers (RM and KM) independently assessed the risk of bias within the studies, using the Risk of Bias Assessment Tool for Nonrandomized Studies (RoBANS).[8] The RoBANS scale comprises 6 domains; Selection of participants, Confounding variables, Measurement of exposure, Blinding of outcome assessments, Incomplete outcome data, and Selective outcome reporting. To every domain, it was assigned "high risk of bias", "low risk of bias", and "unclear risk of bias".

Results

Search and selection results

The study selection process is illustrated in Fig. 1. Of the 1130 studies identified after the initial search; after removing duplicates, 847 studies remained. During the initial stage, 810 studies were excluded based on the evaluation of titles and abstracts (inter-reviewer agreement, kappa statistic = 0.88). Second, after screening the full-text articles of the remaining 37 studies, 13 studies were excluded and the major reasons for exclusion were irrelevant assessment of exposure or outcomes (n = 9) and ineligible participants; younger participants were included

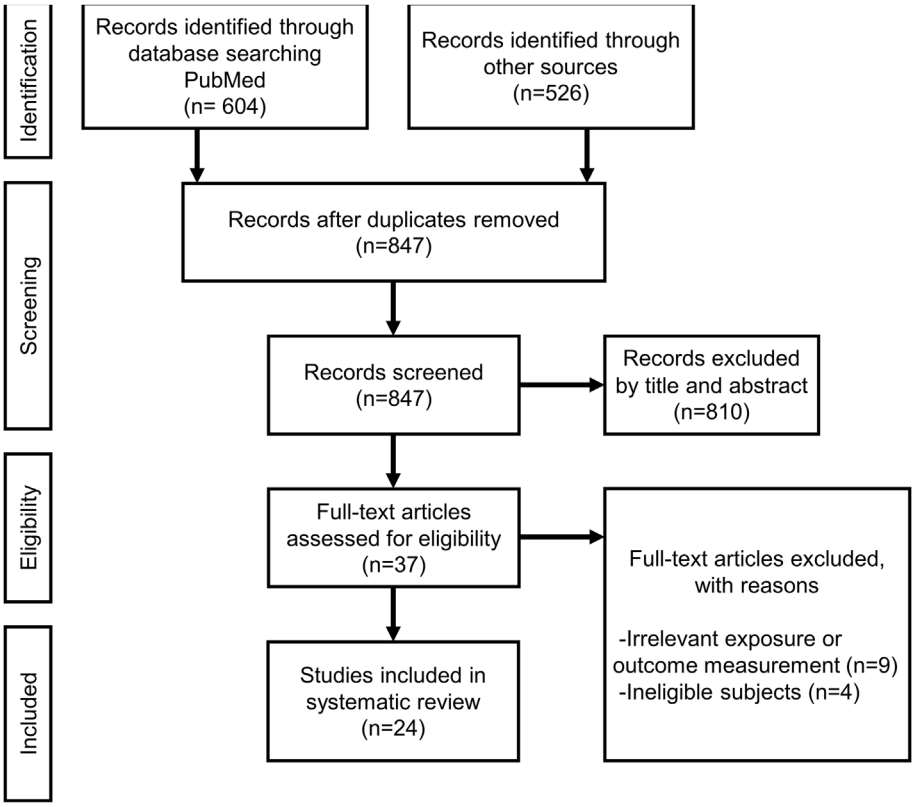

Figure 1 PRISMA flow diagram of the study inclusion criteria.

in the studies (n = 4). Finally, 24 eligible studies were included in this systematic review (inter-reviewer agreement, kappa statistic = 0.94).

Characteristics of included studies

Table 2 summarizes the characteristics of the included studies. Of the 24 studies, three studies were cohort studies[9–11] and 21 were cross-sectional studies.[12–32] Four studies were based on two surveys.[9,10,24,25] Overall, a total of 8684 patients were included in the 24 reports from 22 studies selected. The studies were conducted in 12 countries. Eleven studies[9,10,13,15,19,22,24–26,30] were conducted among community-dwelling individuals and eight studies[12,14,16–18,20,28,29] were conducted with nursing home residents. Most studies included participants ≥60 years of age. Although the minimum age of participants was not mentioned in three studies,[18,28,31] these studies included older participants, with the mean ages of the participants being 85.3,[33] 81,[28] and 70[31] years, respectively.

Assessment of occlusal supports

The methods to assess occluding status are divided into two types among the studies. One method assessed occlusal units that counts areas where occluding at either one of two pairs of premolars or molars at the right and left sides remain. The Eichner Index (modified Eichner Index) was used to assess occlusal units.[16,22,31] The Eichner Index was classified into three types. Eichner A has 4 units and Eichner B has 1–3 units or only anterior occluding tooth pairs. Eichner C has no occluding tooth pair. The other method assesses occluding tooth pairs by counting occluding tooth pairs of maxillary and mandibular teeth.[9–15,17,19–21,23–30,32] As for evaluation of the number of occluding tooth pairs, POPs and FTU were mainly used. POPs was defined as pairs of upper and lower opposing premolars/molars. Two opposing anterior or premolar teeth were defined as one FTU, and those with two opposing molars were defined as two FTUs. The occlusal unit and occluding tooth pairs are shown in Supplementary Fig. 1.

Nutritional assessment

Outcome measurements varied considerably between studies. Some studies evaluated food intake[9,22] and nutrient intake[9,13,22,24,25,31,32] using diet history questionnaires or interviews. Nutritional status was assessed using BMI,[10,11,13,14,17,18,20–22,28–30,32] body cell mass (BCM),[17,21] serum biomarkers of nutritional status,[10,18,29] and MNA or MNA-SF.[11,12,14–16,18–21,23,26] The findings of studies according to the nutritional outcomes were summarized in Table 3.

Assessment of methodological quality

The quality assessment is presented in Figs. 2 and 3. As shown in Fig. 2, some studies were assessed as having a high risk of bias. Concerning the selection of participants, most studies

Table 2 Characteristics of studies included in this systematic review.

Authors	Year	Study design	Study sample	Country	Assessment of occluding area	Nutritional assessment	Covariates	Main findings
van de Rijt et al.[12]	2021	Cross-sectional	111 nursing homes residents, with and without a clinical diagnosis of dementia aged ≥65 years	UK	Number of occlusal units (OU), and functional categories (eg, OU combined with dentures)	MNA-SF	Quality of swallowing, quality of chewing, orofacial pain, summated xerostomia inventory, and soft diet	Almost half of nursing home residents had insufficient oral function, which was negatively associated with nutritional status. After adjusting for the other oral function factors, OU did not remain significant association with nutritional status.
Gaewkhiew et al.[13]	2019	Cross-sectional	788 community-dwelling adults aged ≥60 years	Thailand	Functional dentition defined as having FTUs≥10 including all six anterior contacts and FTUs≥4 from posterior teeth	BMI and Food Frequency Questionnaire (FFQ)	Age, gender, residence area, education, wealth tertiles, smoking status, physical activity, hypertension, hyperlipidemia, diabetes, and total energy intake	Participants with functional dentition were less likely (PR: 0.39, 95% CI: 0.16, 0.95) to be underweight than those with neither functional dentition nor dentures. Participants with functional dentition had significantly greater intake of dietary fibre and Vitamin B1 than those with neither functional dentition nor dentures.
Cocco et al.[14]	2018	Cross-sectional	1493 nursing home residents aged ≥65 years	Italy	Number of FUs	BMI and MNA	The Mini-Mental State Examination (MMSE), age, and sex	MNA was not statistically associated to FUs. BMI was not statistically associated to FUs in multivariate analysis, although their association was significant in univariate model.
Wu et al.[15]	2018	Cross-sectional	195 community-dwelling adults aged ≥65 years	Hong-Kong	Number of occluding tooth pairs	MNA	Age, sex, systemic disease, education, housing condition, past occupation, DFT, periodontal status, and total GOHAI score	Occluding tooth pairs were associated with malnutrition in unadjusted model, but this association was non-significant after controlling for confounding factor in the adjusted models.
Wakabayashi et al.[16]	2018	Cross-sectional	354 individuals aged ≥65 years in need of long-term care	Japan	Modified Eichner Index	MNA-SF	Dysphagia	Path analysis indicated that occlusal support had a direct effect on dysphagia (standard coefficient = 0.33), and that dysphagia was associated directly with malnutrition (standard coefficient = 0.50).
Iwasaki et al.[10]	2018	Cohort	600 community-dwelling adults	Japan	Functional dentition defined	BMI and serum albumin	—	The proportion of low BMI nor low albumin did not differ significantly

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Table 2 (*continued*)

Authors	Year	Study design	Study sample	Country	Assessment of occluding area	Nutritional assessment	Covariates	Main findings
			aged 70 years at baseline; 46.3% attrition (n = 278)		as the presence of more than 20 teeth and nine or more occluding pairs of teeth			between the groups with or without functional dentition.
Tanasić et al.[11]	2016	Cohort	200 patients with partial edentulousness aged ≥65 years at university clinic for prosthodontics	Serbia	Number of FTUs: divided by tooth composition: natural tooth against natural tooth (NN-FTUs), natural tooth against denture (ND-FTUs), and denture against denture (DD-FTUs)	BMI and MNA	–	The results on the MNA changes and BMI changes in 12 months after prosthetic treatment showed that patients with symmetric NN-FTUs had significantly higher values (2.9 ± 0.8 and 1.4 ± 1.0, respectively) compared with patients without NN-FTUs (1.9 ± 0.6 and 1.1 ± 0.4, respectively), or with asymmetric NN-FTUs (1.6 ± 0.4 and 0.7 ± 0.5, respectively).
Iwasaki et al.[9]	2016	Cohort	600 community-dwelling adults aged 70 years at baseline; 52.3% attrition (n = 314)	Japan	Number of FTUs	BDHQ	Sex, education, income, smoking status, activity of daily living, BMI, and comorbidities.	Individuals with FTUs≤5 demonstrated a significantly greater degree of decline in the intake of multiple nutrients (protein, sodium, potassium, calcium, vitamin A, vitamin E and dietary fibre)and food groups (vegetable and meat) than those without FTUs≥5 after adjusting for potential confounders.
Iwasaki et al.[32]	2014	Cross-sectional	353 community-dwelling adults aged 80 years	Japan	Number of POPs and self-reported denture fit	BDHQ	Sex, income, education, smoking status, alcohol use, body mass index, and total calorie intake	The self-reported ill-fitting denture group (POP<8 with self-reported ill-fitting dentures) had significantly lower intake of protein, n-3 polyunsaturated fatty acids, potassium, calcium, vitamin D, vitamin E, vitamin B6, and vitamin B12 than the good dentition group (8 POP and no removable prosthesis) after adjusting for confounders.

Gaszynska et al.[17]	2014	Cross-sectional	259 care homes residents aged ≥65 years	Poland	Number of POPs	BMI and BCM	—	Neither BMI nor BCM associated with posterior tooth pairs.
Poisson et al.[18]	2016	Cross-sectional	159 patients hospitalized in the acute care unit of university hospital with mean age of 85.3	France	Number of POPs	BMI, MNA, serum albumin, and 3-day records of dietary intake	Age, sex, dysphagia, salivary hypofunction, self-feeding autonomy, and autonomy for oral care	Low POPs were not associated with MNA, BMI or serum albumin. Multivariate analysis showed no association between POPs and MNA.
El Osta et al.[19]	2014	Cross-sectional	201 independent elderly attending primary care clinics aged ≥65 years	Lebanon	Number of FUs	MNA	Level of education, perception of xerostomia, GOHAI, prosthetic status, and DMFT index	Participants with FUs≤4 was 2.79 times more likely to be malnourished than participants with participants with FUs≥5 ($P = 0.001$).
Adiatman et al.[20]	2013	Cross-sectional	100 female residents in four private care homes aged ≥60 years	Indonesia	Number of FTUs: divided by tooth composition: natural tooth against natural tooth (NN-FTUs), natural tooth against denture (ND-FTUs), and denture against denture (DD-FTUs)	BMI and MNA	—	Subjects with a normal BMI had a significantly higher total number of FTUs (3.6 ± 4.6) compared with underweight subjects (0.1 ± 0.3). Subjects with a normal MNA had a significantly higher number of NN-FTU (2.6 ± 3.7) compared to those who were at risk or in a state of undernutrition (1.2 ± 2.4).
Solemdal et al.[21]	2012	Cross-sectional	138 patients hospitalized in university hospital for acute medical problems aged ≥70 years	Norway	Number of POPs	BCM and MNA-SF	Age, sex, smoking, education level, hand grip strength, daily medication, body mass index, Cumulative Illness Rating Scale, and MNA-SF	Number of POPs were significantly associated with BCM after adjusting for confounders.
Yoshida et al.[22]	2011	Cross-sectional	182 community-dwelling adults aged ≥65 years	Japan	Eichner Classification	BDHQ	Age and sex	No statistical difference in BMI or intake of macronutrients was found between these two occlusal groups (Eichner A-B3 vs B4 and C). Eichner B4 and C group had significantly less vegetable intake and dietary fiber and significantly more confectionaries than the A-B3 group. There was a significant difference in the intake of various vitamins between the two groups.

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Table 2 (*continued*)

Authors	Year	Study design	Study sample	Country	Assessment of occluding area	Nutritional assessment	Covariates	Main findings
Samnieng et al.[23]	2011	Cross-sectional	612 adults aged ≥60 years	Thailand	Number of FTUs	MNA	Age and sex	After adjusting for age and sex, poor nutritional status was associated with significantly fewer FTUs.
de Andrade et al.[25]	2011	Cross-sectional	887 non-institutionalized elderly people aged ≥60 years	Brazil	Number of POPs	A 24-h diet recall interview	Sex and education	After adjusting for gender and education, participants with no POP were more likely than those with POP≥5 to have inadequate intake of vitamin C (OR = 2.79; 95%CI: 1.16—6.71), calcium (OR = 3.74; 95%CI: 1.69—8.25), riboflavin (OR = 2.49; 95%CI: 1.10—5.64), and zinc (OR = 3.43; 95% CI: 1.07—10.94). The results of multiple linear regression analysis showed that the number of sufficient nutrients and the number of POPs were significantly associated.
Mesas et al.[26]	2010	Cross-sectional	267 non-institutionalized adults aged ≥60 years	Brazil	Number of POPs	MNA	Age, sex, schooling, economic class, smoking, depression, and medication use	The OR of nutritional deficit was significantly higher for no molar occlusal contact (2.18, 95%CI: 1.06—4.45) compared to bilateral molar occlusal contact after adjusting possible confounders.
de Andrade et al.[24]	2009	Cross-sectional	887 non-institutionalized elderly people aged ≥60 years	Brazil	Number of POPs	A 24-h diet recall interview	—	The no POP group had significantly lower nutritional intake of calcium, calories, carbohydrates, iron, phosphorus, and protein than the POP1—4 and POP≥5 groups.
Liedberg et al.[27]	2007	Cross-sectional	481 male adults living in Malmo aged 67—68 years	Sweden	Number of occlusal tooth contacts	Dietary history interview and BMI	—	There was no significant difference in the number of occlusal contacts between the inadequate and adequate nutrition groups, defined based on protein intake and other data obtained from the dietary interview.

Rauen et al.[28]	2006	Cross-sectional	187 institutionalized individuals aged ≥60 years.	Brazil	Number of FTUs	BMI	—	There were significantly more subjects with BMI <18.5 in the group with FTU 1—6 including dentures (group 1) compared to the group with FTU 7—14 including dentures (group 2) and FTU 11—14 with natural teeth only (group 3). There were significantly more people with BMI≥25 in groups 2,3.
Chai et al.[29]	2006	Cross-sectional	120 patients admitted to a convalescent and rehabilitation hospital aged ≥65 years	Hong-Kong	Number of POPs and occlusal contacts of natural teeth or prosthetics	BMI and serum albumin	—	Neither the number of POPs nor occlusal contacts was a significant explanatory factor for malnourished.
Sheiham et al.[30]	2002	Cross-sectional	629 free-living adults aged ≥65 years	UK	Number of POPs	BMI	Age, sex, social class, region of origin, partial denture wearing	The proportion of underweight was significantly higher in those with no POP compared to those with POP≥1 ($P = 0.021$). The OR for overweight in no POP group was 2.7 (95%CI: 1.0—7.3, $p = 0.049$) relative to POP≥5 group.
Osterberg et al.[31]	1982	Cross-sectional	368 adults aged 70 years	Sweden	Eichner Classification	Dietary interview	School education, professional education, marital status, and family yearly income	In multivariate analysis, the Eichner classification was significantly associated with protein and vitamin B1 intake in men. However, no significant association was found in women after adjusting socio-economic factors.

BCM: body cell mass, BDHQ: brief-type self-administered diet history questionnaire, BMI: body mass index, CI: confidence interval, DMFT: the number of decayed, missing, and filled teeth, FU: functional units, FTUs: functional tooth units, GOHAI: General Oral Health Assessment Index, POPs: posterior occluding pairs, MNA: mini nutritional assessment, MNA-SF: mini nutritional assessment short-form, OR: odds ratio.

Table 3 Results for specific foods, nutrients, and nutritional status indicators where at least 2 studies reported the same outcomes.

Outcome	Author	Findings
Food intake		
Vegetables and Fruits	Iwasaki et al.[9]	The degree of decline in vegetable and meat intake was significantly greater in those with impaired dentition than in the other group after adjustment for confounders (−13.6, 95%CI: −25.2 to −2.0, $P = 0.021$). Fruits did not differ between the groups.
	Yoshida et al.[22]	In univariate analysis, Eichner A1-B3 had significantly lower vegetable intake than Eichner B4 and C (179.3 ± 9.9 and 144.4 ± 12.8 g/1000 kcal, $P = 0.048$), but no difference in fruit.
Seafoods and Meats	Iwasaki et al.[9]	The degree of decline in vegetable and meat intake was significantly greater in those with impaired dentition than in the other group after adjustment for confounders (−15.5, 95%CI: −28.3 to −2.7, $P = 0.018$). Fish and shellfish did not differ between the groups.
	Yoshida et al.[22]	In univariate analysis, there were no significant difference in meat and fish intake between Eichner A1-B3 and Eichner B4 and C.
Nutrients intake		
Proteins	Gaewkhiew et al.[13]	Intake of protein was not significantly different by functional dentition groups after adjustment for confounders.
	Iwasaki et al.[32]	The self-reported ill-fitting denture group (POP<8 with self-reported ill-fitting dentures) had significantly lower intake of protein than the good dentition group (POP = 8) after adjusting for confounders ($P = 0.006$).
	Yoshida et al.[22]	In univariate analysis, Eichner A1-B3 had significantly lower protein intake than Eichner B4 and C.
	de Andrade et al.[24]	There was a significant difference in the intake of proteins in the POP = 0, POP = 1—4, and POP = 5—8 groups (56.1 ± 24.9, 68.2 ± 29.7, and 68.4 ± 29.0 mg/day).
	Osterberg et al.[31]	There was a significant correlation between Eichner index and protein intake after adjusting for confounding factors in men, but not in women.
Fibres	Gaewkhiew et al.[13]	Participants with functional dentition consumed 2.69 (95%CI: 0.18—5.36) more grams of dietary fibre than those with neither functional dentition nor dentures.
	Iwasaki et al.[9]	The degree of decline in the intake of dietary fibre was significantly greater in those with impaired dentition than in those without impaired dentition (−6.2, 95% CI: −12.3 to −0.1, $P = 0.045$).
	Iwasaki et al.[32]	The self-reported ill-fitting denture group (POP<8 with self-reported ill-fitting dentures) had significantly lower intake of dietary fiber than the good dentition group (POP = 8) after adjusting for confounders ($P = 0.031$).
	Yoshida et al.[22]	Eichner A1-B3 had significantly lower dietary fiber intake than Eichner B4 and C (8.49 ± 0.28 and 7.36 ± 0.37 g/1000 kcal, $P = 0.036$).
	de Andrade et al.[24]	Dietary fiber intake in the POP=0, POP=1—4, and POP≥5 groups was 8.7 ± 6.8, 10.4 ± 7.3, and 10.1 ± 7.0 mg/day, respectively, and no significant difference was found (ANOVA $P = 0.051$).
Vitamins	Gaewkhiew et al.[13]	Participants with functional dentition consumed 0.66 (95% CI: 0.03—1.29) more milligrams of vitamin B1 than those with neither functional dentition nor dentures.
	Iwasaki et al.[9]	The degree of decline in the intake of vitamin E was significantly greater in those with impaired dentition than in those without impaired dentition (−8.6, 95%CI: 14.8 to −0.7, $P = 0.007$).
	Iwasaki et al.[32]	The self-reported ill-fitting denture group (POP<8 with self-reported ill-fitting dentures) had significantly ($P < 0.05$) lower intake of vitamin D, vitamin E, vitamin B6, and vitamin B12 than the good dentition group (POP = 8) after adjusting for confounders.
	Yoshida et al.[22]	Eichner A1-B3 had significantly lower intakes of carotene, vitamin K, B1, B6, and C than Eichner B4 and C, but no significant differences in Retinol, vitamin D, E, B2, B12, Niacin, Folate, and Pantothenic acid.
	de Andrade et al.[25]	After adjusting for gender and years of education, the ORs for inadequate intake of vitamin C and Riboflavin were significantly higher at 2.79 (95%CI: 1.16—6.71) and 2.49 (95%CI: 1.10—5.64) for POP=0 compared to POP ≥5, respectively.

Table 3 (*continued*)

Outcome	Author	Findings
	de Andrade et al.[24]	There was an increase in vitamin C intake with increasing POP (95.1 ± 220.2, 127.4 ± 244.2, and 150.3 ± 271.9 mg/day in the POP=0, POP=1–4, and POP≥5 groups, respectively) although statistically significant difference was not found (ANOVA $P = 0.093$).
	Osterberg et al.[31]	In multivariate analysis, there was a significant correlation between Eichner index and Thiamin intake in men, but not in women after adjustment for confounders. No significant correlation for Riboflavin in either men or women.
Nutritional status		
BMI	Gaewkhiew et al.[13]	Participants with functional dentition were less likely (prevalence ratio: 0.39, 95% CI: 0.16–0.95) to be underweight than those with neither functional dentition nor dentures.
	Cocco et al.[23]	BMI was statistically associated to functional units. BMI was not statistically associated to functional units in multinomial logistic regression.
	Iwasaki et al.[10]	Low BMI rate did not differ significantly between the groups with or without functional dentition.
	Tanasić et al.[11]	Patients with bilaterally symmetrically placed NN (natural tooth against natural tooth)-FTUs experienced more effective changes in dietary patterns due to significantly higher changes in BMI 12 months after oral rehabilitation compared with patients with asymmetric NN-FTUs or those without NN-FTUs.
	Iwasaki et al.[32]	BMI did not differ between the groups with a variety of dentition.
	Gaszynska et al.[17]	BMI did not associate with POPs.
	Poisson et al.[27]	BMI did not associate with POPs.
	Adiatman et al.[20]	In the three BMI groups (<18.5, 18.5–25,≥25), univariate analysis showed that total FTU (including denture pairing) was significantly lower in the BMI <18.5 group than in the two groups of BMI≥18.5.
	Solemdal et al.[21]	Univariate analysis showed no significant correlation between BMI and POPs.
	Yoshida et al.[22]	BMI tended to be lower in Eichner B4, C compared to Eichner A1-B3 in univariate analysis (22.8 ± 2.8 and 21.9 ± 2,4, $P = 0.075$)
	Rauen et al.[28]	Based on the results of the Chi-square test, there is a higher percentage of BMI<18.5 in 1–6 functional units (FU) and a higher percentage of BMI≥25 in FU>6.
	Chai et al.[29]	In univariate analysis, the group with <6 occlusal contacts had significantly lower BMI compared to the group with ≥6 occlusal contacts (20.97 ± 3.23 and 24.37 ± 4.72). Low POP was not significantly associated with BMI.
	Sheiham et al.[30]	In univariate analysis, POP = 0 group had a significantly higher OR of BMI<20 compared to POP≥1 group ($P = 0.021$). In multivariate analysis, POP=0 group a significantly higher OR of BMI≥30 compared to POP≥5 group(OR = 2.7, 95%CI: 1.0–7.32, $P = 0.049$).
BCM	Gaszynska et al.[27]	BCM did not associate with POPs.
	Solemdal et al.[21]	Multivariate analysis showed that the number of POPs were significantly higher in those with the top quartile of BCM (coefficient: 1.57, 95% CI: 0.21–2.90, $P = 0.024$) compared to the bottom quartile of BCM.
Serum albmin	Iwasaki et al.[10]	The proportion of participants with low albumin (<4 g/dL) did not differ significantly between the groups with or without functional dentition.
	Poisson et al.[18]	Serum albumin did not associate with POPs.
	Chai et al.[29]	No significant difference in serum albumin levels between POP<6 and POP≥6.
MNA or MNA-SF	van de Rijt et al.[12]	Lower number of teeth ($P < 0.001$), lower number of occlusal units ($P < 0.001$), and poorer functional category ($P < 0.001$) were significantly associated with a poorer nutritional status. After adjusting for the other oral function factors, the number of occlusal units did not remain significant association with nutritional status.
	Cocco et al.[14]	MNA was not statistically associated to functional units.
	Wu et al.[15]	Occluding tooth pairs were associated with malnutrition in the unadjusted model (OR: 0.903, 95%CI: 0.844–0.966, $P = 0.003$), but this association was non-significant after controlling for confounding factor in the adjusted models (OR: 0.969, 95%CI: 0.865–1.086, $P = 0.590$).
	Wakabayashi et al.[16]	MNA-SF was significantly different between the functional versus non-functional

(*continued on next page*)

Table 3 (*continued*)

Outcome	Author	Findings
		occlusal support groups ($P = 0.004$).
	Tanasić et al.[11]	Patients with bilaterally symmetrically placed NN (natural tooth against natural tooth)-FTUs experienced more effective changes in dietary patterns due to significantly higher changes in MNA 12 months after oral rehabilitation compared with patients with asymmetric NN-FTUs those without NN-FTUs.
	Poisson et al.[18]	MNA did not associate with POPs in univariate and multivariate analyses.
	El Osta et al.[19]	Participants who had four FUs or fewer were more likely to be malnourished than participants with more than four FUs (OR: 2.79, 95%CI: 1.494−5.218, $P = 0.001$).
	Adiatman et al.[20]	Univariate analysis showed that when MNA was divided into less than 17 and 17−24, the number of FTUs between natural teeth was significantly lower in the group with lower MNA.
	Solemdal et al.[21]	Univariate analysis showed no significant correlation between MNA-SF and POPs.
	Samnieng et al.[13]	At three levels of MNA (23.5+, 7−23, ≤6), FTU was significantly lower at 10.3 ± 0.5, 8.4 ± 0.3, and 8.3 ± 1.1 with decreasing MNA after adjusting for age and gender ($P < 0.05$).
	Mesas et al.[26]	The OR of nutritional deficit (MNA<24) was significantly higher for no molar occlusal contact compared to bilateral molar occlusal contact (2.18, 95%CI: 1.06−4.45).

BCM: body cell mass, BMI: body mass index, CI: confidence interval, FU: functional units, FTUs: functional tooth units, POPs: posterior occluding pairs, MNA: mini nutritional assessment, MNA-SF: mini nutritional assessment short-form, OR: odds ratio.

included either community-dwelling individuals or nursing home residents and were considered representative of the general older population, whereas two studies[11,18] were not considered to represent the general population because those studies were conducted in dental outpatients[11] and acute care hospital inpatients.[18] All studies selected the non-exposed cohort from the same population as the exposed. Regarding confounding variables, eight studies[10,11,17,20,24,27−29] did not adjust for confounding factors with respect to the association between occlusion status and nutrition status. For the measurement of exposure, all studies were performed based on quantitative evaluation and were considered low bias. No studies described blind assessment of the outcomes. Most studies were regarded as low risk of bias in incomplete outcome data. There was insufficient information to assess whether outcomes were selectively reported in any of the included studies.

Descriptive analysis of studies included in the systematic review regarding oral health outcomes and nutritional status

Sixteen[9,11,13,16,19−26,28,30−32] of the 24 included studies reported significant associations between occlusal support and nutritional intake or nutritional status. Of these, seven studies[9,13,22,24,25,31,32] reported a significant association between occlusal support and nutritional intake. In these studies, participants with less occlusal support were associated with lower intakes of vegetable,[9,22] meat[9] food groups and lower intakes of proteins,[9,32] fibers,[9,13,22] and vitamins[9,13,22,25,31,32] as nutrients. Of the studies reporting the association between occlusal support and nutritional status, five reported a significant association between BMI and occlusal support.[11,13,20,28,30] Gaewkhiew et al. reported that individuals with ≥10 FTUs showed significantly lower prevalence ratios (PR) of 0.39 (95% CI: 0.16 to 0.95, $P = 0.0017$) for being underweight (BMI < 18.5) compared to those with FTUs of ≤9 and no denture use, even after adjusting for confounders such as age, sex, socio-economic status (SES), and total energy intake.[13] Six studies[11,16,19,20,23,26] reported a significant association between occlusal support and MNA/MNA-SF. El Osta et al. showed that individuals with ≤4 FUs had a significantly higher odds ratio (OR) of 2.79 (95% CI: 1.494−5.218, $P = 0.001$) for malnutrition (MNA<17) compared to those with ≥5 FUs after adjusting the confounding factors such as Decayed, Missing, and Filled Teeth (DMFT) index and prosthetic status.[19] Mesas et al. reported that individuals with no posterior occlusion showed significantly higher OR of 2.18 (95% CI: 1.06−4.45) for nutritional deficit (MNA<24) compared to those with bilateral posterior occlusion even after adjustment for confounders such as age, sex, SES, and smoking.[26]

On the other hand, eight studies reported no significant association between occlusal support and nutritional intake or nutritional status.[10,12,14,15,17,18,27,29] Three articles[10,18,29] investigated the association between serum albumin, a marker of serum nutritional status, and occlusal support; however, no studies reported a significant association between them. The eight articles assessed nutritional status using BMI and/or MNA (MNA-SF). Of these, several studies reported a significant association between occlusal support and nutritional status in univariate analysis; however, no significant associations were found after adjustment for confounding factors.

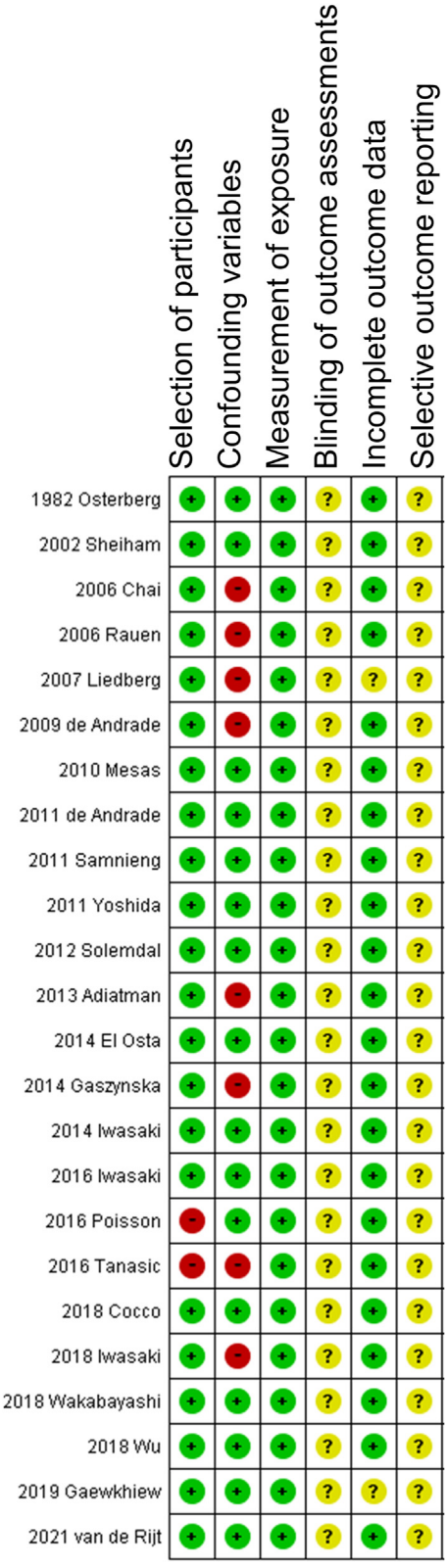

Figure 2 Risk of bias summary: Authors' judgements about each risk of bias item for each included study.

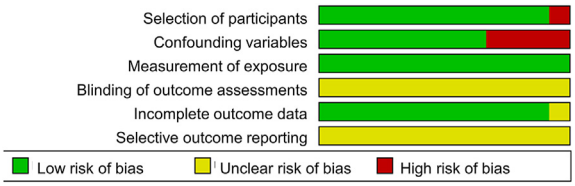

Figure 3 Risk of bias graph: Authors' judgements about each risk of bias item presented as percentages across all included studies.

Discussion

This systematic review identified 24 studies reporting an association between the occluding area and nutritional intake or status in the older population. The studies were conducted in 12 countries and included 8684 participants who were mainly community-dwelling or residents of nursing homes. The occlusal assessment was categorized into two types: one involved an evaluation of the occlusal support area according to the Eichner Classification, and the other included the number of occlusal supports (contact between upper and lower same-named teeth). Nutritional assessment methods were also diverse: ingredient and nutrient intake using food intake surveys, questionnaires such as MNA, and quantitative assessments such as BMI, and serum markers. More than half of the studies concluded that there was an association between occlusal support and nutritional intake or status, while others reported no significant association between them. Interestingly, several studies reported significant associations in univariate analysis, but no significant differences after adjustment for confounding factors such as age, sex, and oral functions other than occlusal support. This suggests that various factors complicate the association between occlusal support and nutrition.

From the previous reports, it is known that poor oral conditions can lead to both overnutrition and undernutrition, and it was found that undernutrition should be emphasized when targeting the older adults. Undernutrition in older adults associates with various systemic diseases.[34,35] Deficient of fruits and vegetables increases the risk cardiovascular disease, diabetes, and some kind of cancers.[34,35] Low protein intake in older adults is associated with a high prevalence of frailty.[36] In this study, we focused on the older adults and investigated the relationship between occlusal status and nutritional status. Previous systematic reviews mainly focused on the association of the number of tooth on nutritional status[37,38] suggested the concroversial conclusions. One systematic review did not report evidence on the effect of tooth loss on diet and nutrition,[37] while the other reported that the malnourished individuals/at risk of malnutrition evaluated with MNA had significantly fewer teeth (standardized mean difference of −0.14; 95% CI: −0.28 to −0.02) than individuals with normal nutrition by a meta-analysis involving five studies.[38]

This difference could be due to the high heterogeneity between included studies. In addition, the number of teeth might not accurately reflect the occlusal function. We considered that occlusal supports more critically affected nutritional status than the number of teeth, therefore we attempted to elucidate the association between occlusal support and nutritional status. Although a meta-analysis could not be performed because of the wide variety of assessments of occlusal and nutrition status in each included article, we have concluded that there may be an association between the amount of occlusal support and nutrition status by a descriptive analysis of the included studies.

A previous study reported that occlusal support was an important predictor of masticatory function.[5] First and second molars contribute 64.7% of the occlusal contact area, with minimal contribution by anterior teeth.[39] Therefore, occlusal support, especially in the molars, plays a major role in chewing ingested food, which could facilitate nutrient absorption into the body, resulting in satisfactory nutritional intake and a favorable condition. The assessment of occlusal support area, which was set as the exposure factor in this systematic review, can more accurately represent the oral function than the number of teeth present.

There are several limitations to this study. First, heterogeneity among the studies was high because of the various outcome assessments and cutoff values in the included reports. Because of the different assessment parameters, quantitative findings from the meta-analysis could not be evaluated. A meta-analysis examining the effect of occlusal support on nutritional status should be conducted when more research is conducted in this area in the future. Second, the participants in this study were older adults, and factors affecting outcomes, such as illnesses and residential environment, were complex. The findings would be more reliable in a multivariate analysis. However, there were some studies with univariate analyses only, that were included in this review. While the majority of participants of the studies included in this systematic review were either community-dwelling or residents of nursing homes, it is important to note that these two groups may be different populations in terms of physical health. Therefore, a stratified meta-analysis should be conducted in the future. Third, because most of the included articles were cross-sectional studies, it was impossible to explore causal relationships. Although there are ethical limitations to a clinical study, future interventional studies should be conducted to validate the causal relationships. The results of this systematic review require careful interpretation because of these limitations, and further well-designed studies are needed.

In conclusion, this systematic review concludes that occlusal support is associated with nutritional intake or status in the older population, although it is necessary to be cautious in interpreting the results due to the methodological limitations of included studies. However, it was also revealed that various confounding factors are involved in the association between occlusal support and nutrition, indicating that further research is required.

Declaration of competing interests

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jds.2023.09.014.

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