Is there a relationship between obesity and tooth loss and edentulism? A systematic review and meta-analysis

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Abstract

This study conducted a systematic review to assess the bi-directional association between tooth loss/edentulism and obesity. Electronic searches were performed in four different databases. Observational studies that tested associations between tooth loss/edentulism and obesity as either exposures or outcomes were included. Additionally, meta-analyses, funnel plots and sensitivity analyses were conducted to synthesize the evidence. A total of 549 articles were identified in the electronic database search. Out of which, 16 studies were included within the meta-analyses: 75% considered tooth loss/edentulism as exposure and obesity as outcome, whereas 25% alternatively considered obesity as exposure and tooth loss/edentulism as outcome. Pooled estimates showed that obese individuals had 1.49 (95%CI 1.20-1.86) and 1.25 (95%CI 1.10-1.42) times higher odds of having any tooth loss and edentulism, respectively. Alternatively, when tooth loss or edentulism were considered as exposures, individuals with tooth loss had 1.41 (95%CI 1.11-1.79) times higher odds for obesity, while edentates had even higher odds (OR 1.60; 95%CI 1.29-2.00). The results indicate a bi-directional association between tooth loss and obesity. Considering that all selected studies were of cross-sectional study design limiting inferences on temporality, longitudinal prospective studies are required to test the causal relationship between tooth loss/edentulism and obesity or vice a versa.

Introduction

Obesity is a highly prevalent chronic disease associated with morbidity and mortality, linked with significant healthcare costs, in both high and low middle income countries (1-3). Obesity is also a well-established risk factor for many systemic conditions, such as type II diabetes, hypertension, cardiovascular disease, infectious diseases and cancer (4, 5). Apart from these general health conditions, evidence further suggests that obesity is associated with oral conditions including dental caries, periodontal disease and tooth loss (6, 7, 8).

Tooth loss is likewise a growing public health concern (9) that reflects cumulative exposure to untreated oral diseases such as dental caries and periodontal disease during the life-course (10, 11). A severe consequence of tooth loss is edentulism, which is identified by the complete absence of teeth within the oral cavity. It is further known to deteriorate individual's quality of life (12). According to the Global Burden of Diseases (GBD) report, severe tooth loss affects 2% of the global population and is listed 36th among the most prevalent chronic diseases that impact life expectancy (13). It is also associated with high economic burden as its treatment, combined with other oral disorders, accounts for approximately 4.7% of overall global health expenditure (14). Several factors such as low socioeconomic status, oral health compromising behaviors such as smoking and high sugar consumption are reported to be associated with tooth loss (15, 16). A negative impact of tooth loss on daily activities such as phonation, eating and socializing is well documented (17). Furthermore, the associations between tooth loss and hypertension, malnutrition and premature mortality is highlighted within the literature (18-19).

Several studies have investigated the association between tooth loss and obesity. But, the direction of this relationship is not clear, as studies have investigated the relationship between tooth-loss and obesity in both directions. Some authors hypothesize that given obesity increases the risk of periodontitis and dental caries; these conditions may ultimately lead to tooth loss (6, 7). Alternatively, others suggest that due to masticatory insufficiency as a consequence of tooth loss, subsequent

alternate dietary choices may lead to obesity. The amount of vegetables, dietary fiber and wholemeal bread consumed is reported to be directly proportional to the number of teeth (20). Hence, there is lack of clarity regarding the direction of association between tooth loss and obesity.

Systematic reviews and meta-analyses have been used to investigate bi-directional associations, as they are tools for producing quality appraised and scientifically reliable information (21). Given the lack of consensus regarding the association between tooth loss/edentulism and obesity within the literature, the current study aims to address this gap by conducting a systematic review of the literature on the association between tooth loss/edentulism and obesity.

Methods

Review Questions

1. Is tooth loss associated with obesity in adults?
2. Is edentulism associated with obesity in adults?
3. Is obesity associated with tooth loss in adults?
4. Is obesity associated with edentulism in adults?

Inclusion and Exclusion Criteria

Original research reported from observational studies that tested associations between tooth loss/edentulism and overweight/obesity, or vice a versa, among adults aged 18 or older were included. As a qualifying condition, all selected studies should have clearly defined obesity or overweight (examination or self-reported) based on measurements such as Body Mass Index (BMI), Waist Circumference (WC) **with explicit cutoff points, respectively.** Similarly, the case definitions for tooth loss/edentulism (examination or self-reported) should be clearly reported by the authors. The case definitions for obesity/overweight and tooth loss/edentulism were accepted as declared by the authors. Animal studies, in vitro studies, letters to the

editor, reviews and studies from non-representative population groups or with explicit convenience sample (institutionalized/hospitalized individuals, vulnerable population, sample selection performed according to the researcher interest) were excluded. Studies in languages other than English, Spanish and Portuguese were also excluded.

Search Strategy

Electronic search were conducted to identify published literature up to July 2015 in databases including PubMed via Medline, Web of Knowledge, Scopus and Scielo for the identification of relevant studies. An initial search was conducted on PubMed with the following MeSH and free terms: “(“Tooth Loss”[Mesh] OR “Tooth Loss”[all] OR “Tooth retention”[all] OR “Missing teeth”[all] OR “Edentulism”[all] OR “Edentulous”[all]) AND (“Obesity, Abdominal”[Mesh] OR “Obesity”[Mesh] OR “Body Fat Distribution”[Mesh] OR “Abdominal Fat”[Mesh] OR “Intra-Abdominal Fat”[Mesh] OR “Body Mass Index”[Mesh] OR “Waist Circumference”[Mesh] OR “Overweight”[Mesh]) OR “Obesity”[all] OR “Overweight”[all])”. No language restrictions were applied within the search.

In the process of title and abstract screening, references were managed using the bibliographic management software EndNote™ X7.4 (Thomson Reuters, New York, NY, US). Duplicate references were excluded. Titles, abstracts and key words were screened based on the aforementioned criteria independently by two reviewers (DAC and CPF). The screened lists were compared and in case of any disagreement, a consensus was reached through discussion. After initial screening of titles and abstract, full articles were evaluated by the same two reviewers. In addition to the electronic search, the reviewers also performed a hand search in the reference list of all included studies. Predefined data-collection worksheets were used for data extraction of each selected publication. This systematic review followed the PRISMA statements for reporting (22).

Quality assessment

The Critical Appraisal Checklist recommended by the Joanna Briggs Institute (23) was used for the quality assessment of selected studies. The checklist composed of 10 items as indicated in (S1). Reviewers should answer 'Yes', 'No' or 'Unclear' for each item. To categorize studies according to quality, an overall score for each study was calculated based on the number of 'Yes' answers. Thus, scores could range from 0 to 10. Finally, studies were categorized into tertiles according to their scores: low quality [total sum between 0-3]; moderate quality [4-6]; high quality [7-10] (24). The same two reviewers (DAC and CPF) conducted quality assessment, and disagreements were resolved by reaching consensus through discussion.

Data extraction

Relevant data was extracted from the selected articles broadly under the categories of study description; exposure and outcome definition; **obesity measure employed and cutoff points**; results on association and methodological quality. Additionally, in order to conduct the meta-analysis, crude and adjusted effect measures (Relative Risk/Odds Ratio) with respective 95% Confidence Intervals (95%CI) were recorded. The corresponding authors were contacted when any further clarifications regarding the study methodology or results were warranted. Data was extracted by two reviewers (DAC and CPF) independently on pre-piloted data extraction forms. In case of any disagreements, discussions were held to resolve and reach consensus. All the stages of this systematic review were supervised by a third reviewer (GGN) who has expertise in systematic reviews methodology.

Data analysis

Four separate meta-analyses were performed to address the four review questions. If a study reported data on more than one review question, data were extracted, entered and analyzed independently in accordance with the question it answered. Results were only pooled when the reported individual estimates from selected studies were adjusted for potential confounders. Combined results were presented as pooled odds ratio. Effect estimates were appropriately converted to odds

ratios when the selected studies measured and reported relative risk (25). Only, the most severe form of tooth loss was included within the meta-analysis when studies reported more than one category of tooth loss (16, 24). For each analysis, pooled odds ratio was estimated using fixed- and random-effect models. In case of heterogeneity (*Chi-square* P-value<0.05 or I^2 >50%), the random-effect model was preferred (26). Additionally, meta-regression and subgroup analyses were performed to investigate if study characteristics influenced between-study variability. Sensitivity analyses were further conducted to estimate and verify the influence of each study on the pooled results. Funnel plot and Egger test were used to test for any potential publication bias (27). All analyses were performed using the software Stata 13.1 (StataCorp, College Station, TX, USA).

Results

Electronic search revealed 549 articles. Out of which, after removing 258 duplicate titles, a total of 291 articles were included for title and abstract screening. Seventy-six articles were included for full text evaluation, and from those 51 were excluded after full text appraisal (Table S1). Subsequently, 25 articles satisfied the inclusion criteria to be included in this systematic review, but only 16 reported data feasible for meta-analysis. Figure 1 displays the PRISMA flow chart for the study selection process. Out of the 16 studies included in the meta-analyses, 12 studies (75%) considered tooth loss/edentulism as exposure and obesity as outcome, whereas four studies (25%) considered obesity as exposure and tooth loss/edentulism as outcome.

The main characteristics of the nine studies included in the review but not in the meta-analyses are presented in Table S2. Based on the quality assessment of the 16 studies included in the meta-analyses, 13 were high quality; three belonged to moderate quality and one was observed to have low quality (Tables 1 and 2).

Table 1 shows the study characteristics of the four articles that tested obesity as an exposure and tooth loss as an outcome. Three studies were carried out in high-income countries (28-30), whereas one was from a middle-income country (31). Collective sample size obtained from these studies was of 9,085 individuals aged 18 years and above. All studies used BMI (clinical measured and self-reported) as a measurement or marker of obesity. Meta-analysis for the association between obesity and tooth loss showed that obese individuals had 1.49 times higher odds (95%CI 1.20-1.86) of any tooth loss (Figure 2A) and 1.25 times (95%CI 1.10-1.42) higher odds of edentulism (Figure 2B). Due to the low number of studies included for this direction of association, funnel plot and Egger test were not performed.

Table 2 reports the main findings of the studies that considered tooth loss as an exposure and obesity as outcome. Twelve studies were included in the analyses, comprising a total of 32,535 individuals aged 20 years and above. Five studies were conducted in Brazil (20, 32-35), three in Sweden (36-38), one in Sri Lanka (39), one in France (40), one in the United States of America (41), and one in the United Kingdom (42). Eleven studies considered any tooth loss as exposure and nine considered edentulism as the exposure (Table 2). Individuals with any tooth lost and edentates presented 41% (Figure 3A) and 60% (Figure 3B) higher odds of obesity, respectively (OR 1.41; 95%CI 1.11-1.79; OR 1.60; 95%CI 1.29-2.00). Meta-regression analyses revealed that age of participants and type of tooth loss assessment explained 2.9% and 9.6% of heterogeneity in the “edentulism to obesity” model. Moreover, obesity assessment and the study setting explained about 21% and 17% of heterogeneity, respectively in the “obesity to tooth loss” model (Tables S3 and S4). The Egger test showed the presence of small-study effect ($P=0.004$) when any tooth loss was considered as an exposure. But, similar effect was not observed when edentulism was set as the exposure variable ($P=0.666$). These findings are reported in the funnel plots (Figures 4A and 4B). The findings from the sensitivity analysis confirmed that the omission of any study would not modify the association of any performed analyses as indicated by Figures S1 (Figure S1A: Obesity to tooth loss;

S1B: Obesity to edentulism) and S2 (S2A: Tooth loss to obesity; S2B: Edentulism to obesity) (Supporting information).

Discussion

The positive associations observed in all meta-analyses confirmed the association between tooth loss/edentulism and obesity. Additionally, the findings from the performed sensitivity analyses reinforces the robustness of our findings. It is noteworthy that the evidence is mainly informed from cross-sectional studies, which precludes the establishment of temporal and causal relationship between the exposures and outcomes. In order to circumvent this issue, articles that considered both tooth loss and obesity as either exposure or outcome were included in this review. The literature base from the current review revealed that 75% of the studies considered tooth loss/edentulism as exposure and obesity as outcome. The causality in any direction of this association cannot be established from the available evidence, but findings from this systematic review may be relevant for both clinicians and policy makers. Even though similar results have been observed in individual studies, meta-analyses are considered robust sources of evidence as they amplify the statistical power. To the best of authors' knowledge, this is the first systematic review and meta-analysis informing this topic.

Findings from the current study demonstrated a positive association when tooth loss or edentulism were set as exposures and obesity as outcome. According to the results, individuals with any tooth loss had higher odds of being obese, and these odds were comparatively even higher among edentates. Studies have reported that tooth loss impacts masticatory sufficiency, which can consequently lead to alternate dietary choices (41). Moreover, it has been demonstrated that lower number of teeth is inversely associated with the intake of vegetables, fruits and dietary fibers (35, 40). It is also reported that this reduction in consumption of healthy food is independent of the effects of lower social position on lack of nutritional intake (43, 44). A recent

study using data from the Brazilian National Oral Health Survey (SB 2010) highlighted that higher number of missing teeth combined with absence of appropriate prosthetic rehabilitation negatively impacts eating abilities (45). Edentulism or the complete absence of teeth in the oral cavity also impacts both on the quality as well as type of diet. Sheiham et al. (42) demonstrated that compared to those with some natural teeth, edentates have even worse quality of food intake. This appears as a potential explanation for our findings, since edentates presented even higher odds of being obese compared to those with some loss of teeth. The literature has also emphasized on the role of oral rehabilitation with the replacement of missing teeth in this association. According to Torres et al., dental prosthesis could mitigate the masticatory insufficiency caused due to tooth loss, thus retaining a protective effect on obesity (34). Hence, the findings of the study have key implications for public health policy considering obesity, dietary change and dietary quality are also well-established risk factors for other life threatening chronic diseases, such as cardiovascular disease and cancer (46).

On the other hand, obesity is also identified as a risk factor for tooth loss. Studies have shown that obesity induces a chronic low-grade generalized inflammation that is generated by a combination of factors. It is hypothesized that the adipose tissue works as an endocrine organ, secreting pro-inflammatory cytokines such as interleukins and tumor necrosis factors in the blood stream (47). Additionally, the expansion of adipocytes constrains blood vessels that are responsible for cellular nutrition. This condition stimulates the recruitment of macrophages to the core of the adipose tissue, exacerbating the inflammatory load in an upregulation feedback (48). Consequently, the inflammatory condition reduces the individuals' immune threshold making obese individuals more susceptible to periodontal disease, a major reason for tooth loss (4, 7, 49). Furthermore, it has been demonstrated that obesity negatively impacts on the salivary flow leading to hyposalivation, which in turn increases the risk of dental caries (6, 50). Findings from the current review also substantiate this hypothesis as obese individuals were observed to have higher probability of both losing any tooth and being completely edentate.

Some methodological details and limitations of this review should be highlighted. First, different measures and definitions of both tooth loss and edentulism were adopted within the selected studies. Four studies (20, 29, 31, 32) used self-reported tooth loss and two studies used self-reported BMI and tooth loss (28, 38). Self-reported tooth loss and BMI are validated measures of tooth loss and obesity (51, 52) and are also useful instruments for data collection particularly in large epidemiological studies. Despite the use of self-reported information, sensitivity analyses revealed that the omission of any study would not eliminate the observed associations in the combined results; thus no significant impact on the findings (Figures S1 and S2). Moreover, the meta-regression analysis further established that self-reported information was not a relevant source of heterogeneity (Tables S3 and S4). Second, it was not possible to determine the specific causes of tooth loss in the included studies. Despite the lack of this information, previous investigations have shown that the main reasons for population levels of tooth loss are untreated dental caries and periodontal disease (11). Since tooth loss reflects a cumulative experience throughout the life-course, the accuracy of its cause maybe undermined by recall bias. Regardless of the difficulty to precisely identify the main cause for tooth loss, it is recognized that obesity increases both the risk of dental caries and periodontal disease. Additionally, both conditions share common risk factors, such as social disadvantage, neglected oral health hygiene habits, poor health behaviors such as high sugar consumption and general health problems. Therefore, based on the literature, it can be well assumed that dental caries and periodontal disease were the main reasons of tooth loss in the included studies. Third, the cross-sectional design of all included studies precluded the establishment of a causal relationship between tooth loss and obesity. Considering that both obesity and tooth loss are chronic and long-term conditions, the potential absence of longitudinal studies studying associations between these two conditions is likely. This relates to the fact that such longitudinal studies will demand long follow-up period. But, the bi-directional association observed in the current review indicates the need to understand the plausibility and temporality of both directions. Considering that reverse causality cannot be overruled, it is important

to test the longitudinal relationships between tooth loss and obesity, or vice versa, underpinned by plausible theoretical mechanisms. Fourth, the inclusion of both adults and older adults in the same analysis could have misrepresented our results, since tooth loss and edentulism are positively associated with ageing. In order to avoid this potential caveat, subgroup and meta-regression analysis were performed. The results revealed no relevant influence of the age of participants as a potential source of heterogeneity (Tables S3 and S4). On the other hand, self-reported BMI overestimated the magnitude of the association in the “obesity to tooth loss” model. Finally, the heterogeneity explained by the study setting in this model should be carefully considered, as only one selected study was conducted in a middle-income country.

Regardless of the limitations, our review has strengths that should be highlighted. The meta-analyses initially enrolled approximately 40,000 individuals. Hence, a large sample size provides robustness to our findings. Furthermore, limiting the inclusion of only adjusted estimates in the meta-analyses reduces the likelihood of bias and confounding. However, a possibility of residual confounding cannot be ruled out; besides, a certain degree of measurement error is expected, what might have contributed as a source of bias. In addition, the use of sensitivity analysis, subgroup analysis and meta-regression further confirms the robustness of our findings. Ultimately, the inclusion of studies that considered both tooth loss/edentulism and obesity as exposure or outcome allowed us to explore different perspectives on directions of this association.

The results of our systematic review and meta-analyses clearly demonstrated an association between tooth loss/edentulism and obesity. Nevertheless, as this evidence is derived from cross-sectional studies, it precluded us to establish a causal relationship between the exposure and outcome. Thus, our findings strongly suggest that further studies with prospective design and long-term follow up are necessary, in order to address the causal relationship between tooth loss and obesity, and obesity and tooth loss likewise. Given that both obesity and tooth loss/edentulism share

common risk factors, a common risk approach of integrating oral and general health preventive approaches appears as a useful health promotion and public health strategy.

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Figures legends

Figure 1. Flow diagram of studies selection;

Figure 2. A. Pooled effect of obesity on tooth loss. Data are presented as odds ratio for each study (boxes), 95% CIs (horizontal lines) and summary as odds ratio with 95% CI (diamond). **B.** Pooled effect of obesity on edentulism. Data are presented as odds ratio for each study (boxes), 95% CIs (horizontal lines) and summary as odds ratio with 95% CI (diamond).

Figure 3. A. Pooled effect of tooth loss on obesity. Data are presented as odds ratio for each study (boxes), 95% CIs (horizontal lines) and summary as odds ratio with 95% CI (diamond). **B.** Pooled effect edentulism on obesity. Data are presented as odds ratio for each study (boxes), 95% CIs (horizontal lines) and summary as odds ratio with 95% CI (diamond).

Figure 4. A. Funnel plot of studies exploring the association between tooth loss and obesity. **B.** Funnel plot of studies exploring the association between edentulism and obesity.

Table legends

Table 1. Main findings of the studies included in the meta-analysis that considered obesity as exposure and tooth loss as outcome. *Data included in the meta-analysis for any tooth loss; **Data included in the meta-analysis for edentulism. BMI: Body Mass Index; OR: Odds Ratio; yo: years-old.

Table 2. Main findings of the studies included in the meta-analysis that considered tooth loss as exposure and obesity as outcome. *Data included in the meta-analysis for any tooth loss; **Data included in the meta-analysis for edentulism. BIA: Bioelectrical Impedance Analysis; BMI: Body Mass Index; OR: Odds Ratio; WC: Waist Circumference; WHR: Waist-Hip Ratio; yo: years-old.

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Table 1. Main findings of the studies included in the meta-analysis that considered obesity as exposure and tooth loss as outcome

Author/Year	Setting	Study Design	Sample	Measure of nutritional status	Nutritional status cut-off point	Measure of tooth loss	Tooth Loss cut-off point	Analytical Approach	Crude Results with 95% CI	Adjusted Results with 95% CI	Adjustment	Direction of Association	Quality of the evidence
Jiang et al., 2013 (28)	United States of America	Cross-sectional	2,750 individuals aged 18 or older	Self-reported Body Mass Index (BMI)	BMI Obesity ≥ 30	Self-reported number of teeth	1-5 missing teeth 6-31 missing teeth Edentulous	Multinomial Logistic regression	None	<p>18-44 yo</p> <p>1-5 Missing teeth Obese OR 1.09 (0.93-1.26)</p> <p>6-31 Missing teeth Obese OR 1.33 (0.99-1.79)*</p> <p>Edentulous Obese OR 0.98 (0.44-2.19)**</p> <p>45-64 yo</p> <p>1-5 Missing teeth Obese OR 1.14 (1.04-1.26)</p> <p>6-31 Missing teeth Obese OR 1.22 (1.06-1.40)*</p> <p>Edentulous Obese OR 1.42 (1.14-1.79)**</p> <p>≥ 65 yo</p> <p>1-5 Missing teeth Obese OR 1.04 (0.90-1.20)</p> <p>6-31 Missing teeth Obese OR 1.30 (1.12-1.51)*</p> <p>Edentulous Obese OR 1.20 (1.01-1.43)**</p>	Age Income Education Smoking Physical Activity Diabetes Disability Dental Insurance	Obesity to Tooth Loss	Moderate
Jung et al., 2011 (29)	Korea	Cross-sectional	1,091 individuals aged 65	Body Mass Index (BMI)	BMI Overweight /Obesity ≥ 25	Self-reported number of teeth	Edentulous	Multivariable Logistic regression	Edentulous Overweight OR 1.01 (0.68–1.50)	Edentulous Overweight OR 1.07 (0.72–1.59)**	Age Gender Residential area	Obesity to Tooth Loss	High

Ojima et al., 2007 (30)	Japan	Cross-sectional	1,314 individuals aged 20 to 39	Body Mass Index (BMI)	BMI Overweight /Obesity ≥ 25	Number of teeth	≥ 1 missing teeth	Multivariable Logistic regression	None	Males Overweight OR 1.28 (0.83-1.96)* Females Overweight OR 2.00 (1.31-3.04)*	Frequency of toothbrushing Alcohol Consumption Intake of vitamins C and E	Obesity to Tooth Loss	Low
Pilotto et al., 2013 (31)	Brazil	Cross-sectional	3,930 adults aged 20 to 59	Body Mass Index (BMI)	BMI Overweight 25-30 Obesity ≥ 30	Self-reported number of teeth	≥ 1 missing teeth	Multivariable Logistic regression	Overweight OR 1.64 (1.44-1.88) Obesity OR 2.12 (1.79-2.51)	Overweight OR 0.80 (0.57-1.12) Obesity OR 0.86 (0.60-1.23)*	Demographic variables Dietary variables Health services Health behaviors Socioeconomic variables	Obesity to Tooth Loss	Moderate

*Data included in the meta-analysis for any tooth loss; **Data included in the meta-analysis for edentulism.

BMI: Body Mass Index; OR: Odds Ratio; yo: years-old.

Table 2. Main findings of the studies included in the meta-analysis that considered tooth loss/edentulism as exposure and obesity as outcome

Author/Year	Setting	Study Design	Sample	Measure of nutritional status	Nutritional status cut-off point	Measure of tooth loss	Tooth Loss cut-off point	Analytical Approach	Crude Results with 95% CI	Adjusted Results with 95% CI	Adjustment	Direction of Association	Quality of the evidence
Bernardo et al., 2012 (32)	Brazil	1,720 individuals aged 20 to 59	Cross-sectional	Body Mass Index (BMI) Waist Circumference (WC)	BMI Obesity ≥ 30 WC Obesity >88cm in women >102cm in men	Self-reported number of teeth	≥ 10 in both arches (ref) <10 teeth in at least one arch Edentulous	Multivariable Poisson regression	BMI <10 in at least one arch OR 2.05 (1.49-3.07) Edentulous OR 1.91 (0.88-5.46) WC <10 in at least one arch OR 2.33 (1.61-3.37) Edentulous OR 3.78 (1.75-10.0)	<u>BMI</u> <10 teeth in at least one arch OR 1.24 (0.88-2.2)* Edentulous OR 0.9 (0.46-2.05)** <u>WC</u> <10 teeth in at least one arch OR 1.0 (0.7-1.48) Edentulous OR 1.0 (0.6-1.61)	Number of natural teeth Gender Monthly per capita family income Self-reported diabetes Education level Age	Tooth Loss to Obesity	High
Benguigui et al., 2012 (40)	France	186 individuals aged 35 to 64	Cross-sectional	Body Mass Index (BMI)	BMI Overweight 25-30 Obesity ≥ 30	Number of teeth	0 missing teeth (ref) 1-2 missing teeth 3-27 missing teeth	Multinomial Logistic regression	None	1-2 missing teeth OR 1.39 (0.67–2.90) 3-27 missing teeth OR 1.72 (0.81–3.62)*	Age Gender Education level Smoking habits Physical activity Energy intake C-reactive protein "High-carbohydrate" diet Insulin	Tooth Loss to Obesity	Moderate

De Marchi et al., 2012 (35)	Brazil	471 individuals aged 60 or older	Cross-sectional	Bioelectrical Impedance Analysis (BIA)	BIA Obesity Women >36% Men >25%	Number of teeth	>8 natural teeth (ref) 1-8 natural teeth Edentulous using one denture Edentulous using both dentures	Multinomial Logistic regression	1-8 missing teeth OR 1.21 (0.72–2.05) Edentulous using one denture OR 2.12 (0.85–5.31) Edentulous using both dentures OR 1.67 (1.01–2.76)	1-8 missing teeth OR 1.37 (0.79–2.37)* Edentulous using one denture OR 2.87 (1.09–7.53)** Edentulous using both dentures OR 1.82 (1.05–3.16)	Age Income Urban or Rural Marital status Smoking status Race Gender Schooling Presence of chronic conditions	Tooth Loss to Obesity	High
Hilgert et al., 2009 (33)	Brazil	783 individuals aged 60 or older	Cross-sectional	Body Mass Index (BMI)	BMI Obesity ≥30	Number of teeth	>8 natural teeth (ref) 1-8 teeth wearing one removable denture or none 1-8 teeth wearing two removable dentures Edentulous wearing both dentures Edentulous wearing upper denture	Multivariable Logistic regression	1-8 teeth wearing one removable denture or none OR 3.00 (1.75–5.16) 1-8 teeth wearing two removable dentures OR 1.64 (0.95–2.85) Edentulous wearing both dentures OR 1.24 (0.80–1.93) Edentulous wearing upper denture OR 2.89 (1.52–5.52)	1-8 teeth wearing one removable denture or none OR 2.96 (1.88–5.19)* 1-8 teeth wearing two removable dentures OR 1.37 (0.78–2.43) Edentulous wearing both dentures OR 0.84 (0.52–1.34) Edentulous wearing upper denture OR 2.34 (1.18–4.27)**	Demographic variables Socio-economic variables Co-morbidities Current smoking	Tooth Loss to Obesity	High

Östberg et al., 2009 (36)	Sweden	2,761 individuals aged 30 to 74	Cross- sectional	Body Mass Index (BMI) Waist Circumferenc e (WC)	BMI Obesity ≥30 WC Obesity ≥102cm for men Obesity ≥88cm for women	Numbe r of teeth	20 or more teeth (ref) Less than 20 teeth	Multivariab le Logistic regression	<u>BMI</u> <u>30-74 yo</u> >10 missing teeth OR 1.70 (1.34-2.15) <u>30-<60 yo</u> >10 missing teeth OR 2.17 (1.51-3.12) <u>≥60-74 yo</u> >10 missing teeth OR 0.86 (0.58-1.26) <u>WC</u> <u>30-74 yo</u> >10 missing teeth OR 2.04 (1.64-2.53) <u>30-<60 yo</u> >10 missing teeth OR 2.23 (1.58-3.15) <u>≥60-74 yo</u> >10 missing teeth OR 1.13 (0.79-1.61)	<u>BMI</u> <u>30-74 yo</u> >10 missing teeth OR 1.02 (0.74-1.40)* <u>30-<60 yo</u> >10 missing teeth OR 1.67 (1.10-2.54) <u>≥60-74 yo</u> >10 missing teeth OR 0.73 (0.44-1.19) <u>WC</u> <u>30-74 yo</u> >10 missing teeth OR 1.21 (0.90-1.63) <u>30-<60 yo</u> >10 missing teeth OR 1.72 (1.15-2.59) <u>≥60-74 yo</u> >10 missing teeth OR 1.09 (0.68-1.74)	Age Gender Educational level Marital status Ethnic origin Tobacco use Physical activity Social participation Hypertension Cardiovascular disease Diabetes	Tooth Loss to Obesity	High
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Östberg et al., 2012 (37)	Sweden	999 women aged 38 to 60	Cross-sectional	Body Mass Index (BMI) Waist Circumference (WC) Waist-hip-ratio (WHR)	BMI Obesity ≥ 30 WC Obesity $> 88\text{cm}$ WHR Obesity $\geq 80\text{cm}$	Number of teeth	20 or more teeth (ref) Less than 20 teeth	Multivariable Logistic regression	<u>BMI</u> Number of teeth (continuous variable) OR 0.96 (0.95-0.98) >10 missing teeth OR 1.95 (1.40-2.73) <u>WC</u> Number of teeth (continuous variable) OR 0.96 (0.95-0.98) >10 missing teeth OR 1.94 (1.47-2.55) <u>WHR</u> Number of teeth (continuous variable) OR 0.97 (0.96-0.99) >10 missing teeth OR 1.67 (1.28-2.19)	<u>BMI</u> Number of teeth (continuous variable) OR 0.97 (0.95-1.00) >10 missing teeth OR 1.67 (1.10-2.55)* <u>WC</u> Number of teeth (continuous variable) OR 0.97 (0.95-0.99) >10 missing teeth OR 1.60 (1.13-2.28) <u>WHR</u> Number of teeth (continuous variable) OR 0.98 (0.96-1.00) >10 missing teeth OR 1.48 (1.05-2.07)	Age SES Life style Anxiety Co-morbidity	Tooth Loss to Obesity	High
Österberg et al., 2010 (38)	Sweden	16,416 individuals aged 55 to 84	Cross-sectional	Self-reported Body Mass Index (BMI)	BMI Obesity $\geq 30 \text{ kg/m}^2$	Self-reported number of missing teeth	Dentate (ref) Edentulous	Multivariable Logistic regression	None	<u>Females</u> Edentulous OR 1.80 (1.48-2.17)** <u>Males</u> Edentulous OR 1.26 (1.00-1.59)**	Age Year of investigation Education Occupation Economic problems Native born Urbanization Smoking Feeling healthy Chronic disease	Tooth Loss to Obesity	High

											Handicap Physical activity Body height		
Perera & Ekanayake, 2012 (39)	Sri Lanka	480 individuals aged 60 or older	Cross-sectional	Body Mass Index (BMI)	BMI Overweight ≥ 25	Number of missing teeth	0-19 missing teeth (ref) 20-32 missing teeth	Multinomial Logistic regression	None	20-32 missing teeth OR 0.96 (0.94-1.04)*	Gender Ethnicity Denture Status	Tooth Loss to Obesity	High
Sheiham et al., 2002 (45)	United Kingdom	629 individuals aged 65 or older	Cross-sectional	Body Mass Index (BMI)	BMI Overweight 25-30 Obesity ≥ 30	Number of teeth	Edentulous 1-10 remained teeth 11-20 remained teeth 21-32 remained teeth (ref)	Multivariable Logistic regression	None	<u>Overweight</u> 1-10 OR 1.7 (0.76-3.91) 11-20 OR 1.9 (0.94-3.69) Edentulous OR 1.2 (0.54-2.51) <u>Obesity</u> 1-10 OR 3.1 (1.08-8.84) 11-20 OR 3.3 (1.29-8.22)* Edentulous OR 2.3 (0.78-6.77)**	Age Sex Social Class Region of Residence Partial denture wearing	Tooth Loss to Obesity	High

Singh et al., 2015 (20)	Brazil	1,704 individuals aged 60 or older	Cross-sectional	Body Mass Index (BMI) Waist Circumference (WC)	BMI Obesity ≥ 30 WC Obesity >88cm in women >102cm in men	Self-reported number of teeth	≥ 10 teeth in both arches (ref) ≤ 10 teeth in at least one arch Edentate	Multivariable Logistic regression	<u>BMI</u> ≤ 10 teeth in at least one arch OR 1.1 (0.8-1.7) Edentulous OR 1.2 (0.8-1.7) <u>WC</u> ≤ 10 teeth in at least one arch OR 1.1 (0.8-1.6) Edentulous OR 1.4 (1.1-1.9)	<u>BMI</u> ≤ 10 teeth in at least one arch OR 1.1 (0.7-1.6)* Edentulous OR 1.0 (0.6-1.7)** <u>WC</u> ≤ 10 teeth in at least one arch OR 1.0 (0.7-1.5) Edentulous OR 1.3 (0.8-2.1)	Demographic variables Socioeconomic variables Gender Smoking Physical activity Use of dentures Hypertension Diabetes	Tooth Loss to Obesity	High
Torres et al., 2013 (34)	Brazil	875 individuals aged 65 or older	Cross-sectional	Body Mass Index (BMI)	BMI Overweight 28-30 Obesity ≥ 30	Number of teeth	≥ 20 natural teeth (ref) ≥ 20 teeth without prosthesis <20 teeth with prosthesis <20 teeth without prosthesis Edentulous wearing both dentures Edentulous wearing none or one denture	Multinomial Logistic regression	≥ 20 teeth without prosthesis OR 0.99 (0.47–2.10) <20 teeth with prosthesis OR 1.20 (0.71–2.05) <20 teeth without prosthesis OR 1.60 (0.70–3.69) Edentulous wearing both dentures OR 1.57 (0.94–2.62) Edentulous wearing none or one denture OR 1.87 (0.95–3.67)	≥ 20 teeth without prosthesis OR 1.07 (0.38–2.97) <20 teeth with prosthesis OR 1.42 (0.71–2.80) <20 teeth without prosthesis OR 1.41 (0.42–4.68)* Edentulous wearing both dentures OR 1.68 (0.85–3.35) Edentulous wearing none or one denture OR 2.88 (1.12–7.40)**	Age Gender Skin color Marital Status Education Family income Medication intake Smoking Physical Activity Depression Oral Health status Eating difficulties	Tooth Loss to Obesity	High

Zhu and Hollis, 2015 (41)	United States of America	5,511 individuals aged 20 or older	Cross-sectional	Waist Circumference (WC)	WC Obesity >88cm in women >102cm in men	Number of teeth	0 missing teeth (ref) 1-7 missing teeth 8-27 missing teeth Edentulous	Multivariable Logistic regression	1-7 missing teeth OR 1.90 (1.64-2.20) 8-27 missing teeth OR 3.14 (2.57-3.85) Edentulous OR 4.53 (3.53-5.81)	1-7 missing teeth OR 1.40 (1.20-1.63) 8-27 missing teeth OR 1.46 (1.13-1.89)* Edentulous OR 1.80 (1.27-2.56)**	Age Gender Skin color Education Family income Smoking Physical activity Energy intake	Tooth Loss to Obesity	High
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*Data included in the meta-analysis for any tooth loss; **Data included in the meta-analysis for edentulism.

BIA: Bioelectrical Impedance Analysis; BMI: Body Mass Index; OR: Odds Ratio; WC: Waist Circumference; WHR: Waist-Hip Ratio; yo: years-old.

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