Journal of Dentistry 43 (2015) 1051–1059

Contents lists available at ScienceDirect

Journal of Dentistry

journal homepage: www.intl.elsevierhealth.com/journals/jden

Review article

Tooth loss in adults and income: Systematic review and meta-analysis

Lenise M. Seerig[a], Gustavo G. Nascimento[b,c], Marco A. Peres[c], Bernardo L. Horta[a], Flávio F. Demarco[a,b,*]

[a] Post-graduate Program in Epidemiology, Federal University of Pelotas, Pelotas, Brazil
[b] Post-graduate Program in Dentistry, Federal University of Pelotas, Pelotas, Brazil
[c] Australian Research Centre for Population Oral Health, The University of Adelaide, Adelaide, Australia

ARTICLE INFO

Article history:
Received 12 January 2015
Received in revised form 28 June 2015
Accepted 1 July 2015

Keywords:
Tooth loss
Tooth mortality
Socioeconomic Position
Income

ABSTRACT

Objective: To systematically review the literature in order to identify an association between income and tooth loss in adults.
Methods: An electronic search was conducted on PubMed, Scopus, Embase, Web of Knowledge, Scielo and LILACS. Studies were included if they reported the relationship between socioeconomic status (assessed by income) and tooth loss (clinical examination or self-reported) among adults aged from 18 to 60-years-old.
Results: We, found 1007 articles through March 2014; 11 studies were then included. The results of meta-analyses with random-effects model that subjects of lower levels of income presented greater chance of tooth loss (OR 2.52; 95%CI 2.11–3.01). This association also remained significant when only adjusted results were pooled; however, attenuation in the magnitude of such association was noted (OR 1.66; 95% CI 1.48–1.86) as well as no heterogeneity. Meta-regression analysis revealed that the sample size explained about 9% of heterogeneity in the crude model.
Conclusion: Our results evidenced a relationship between income and tooth loss in adults. Longitudinal studies with broader socioeconomic measures are encouraged.

1. Introduction

Among several socioeconomic position measures employed in epidemiology, income is one of the most relevant for reflecting material conditions and for being the most direct way of measuring socioeconomic position [1]. In most situations, the lower the income the higher the prevalence of health problems [2]. Thus, those living in poverty concentrate greater load oral diseases, such as dental caries and periodontitis [3], and systemic conditions, such as diabetes, cardiovascular disease and obesity [4]. Given that, the association between income and unfavorable health conditions is beyond dispute in the literature.

Oral health conditions provide an excellent model for investigating the impact of income on health conditions, since the most common dental disorders are easily-recognized indicators of past disease experience, with an etiology that comprises a complex mix of social, biological and behavioral factors [5]. The practices that create the oral health inequities are embedded in the usual patterns of ordinary life [6], and follow the general health conditions: some are socially determined and differ across the economic hierarchy, presenting worse oral health status [7].

Tooth loss is a worldwide public health issue, especially in low- and middle-income countries [4,8]. It is associated with general health conditions such as blood pressure, obesity and malnutrition, also considered a potential risk factor to cardiovascular disease [9–12]. Furthermore, this condition impacts negatively on the quality of life [13], affecting daily activities like chewing, swallowing, phonation, esthetics and social life [10,13,14]. According to Marcenes and colleagues, severe teeth loss is ranked in the 36th position among the 100 chronic diseases that affect life expectation, reflecting the importance of this condition considering not only oral, but also the systemic health [8].

Many reports have demonstrated the close relationship between income and tooth loss, emphasizing the relevance of such topic. However, in some of them this association is not noted, due to issues such as small sample size and lack of statistical power. Based on that, it is a concern that no systematic review has thus far explored such association. Therefore, this study aimed to conduct a systematic

* Corresponding author at: School of Dentistry, Federal University of Pelotas 457 Gonçalves Chaves St, room 506 96015-560, Pelotas, RS, Brazil.
Fax: +55 53 3225 6741.
E-mail address: ffdemarco@gmail.com (F.F. Demarco).

http://dx.doi.org/10.1016/j.jdent.2015.07.004
0300-5712/

review and meta-analysis in order to investigate the association between income and tooth loss in adults.

2. Methods

2.1. Review question

The review question was based on the modified "PICO question" for observational studies as follows: "Is there an association between income and tooth loss in adults aged 18–60-years-old?".

2.1.1. Search strategy

An electronic search was conducted in March 2014, in a structured way to identify manuscripts that analyzed the association between income and tooth loss in adults. Electronic database searches of PubMed via Medline, Scientific Electronic Library Online (SciELO), Web of Knowledge and Scopus were performed up to and including March 2014 using MeSH terms and other keywords in several combinations. No date restriction was applied.

We combined each of the following terms for income: "Factors, Socioeconomic" [Mesh] or "Factors, Socioeconomic" or "Factor, Socioeconomic" or "Socioeconomic Factor" or "Standard of Living" or "Living Standard" or "Living Standards" or "Low-Income Population" or "Low Income Population" or "Low-Income Populations" or "Population, Low-Income" or "Populations, Low-Income" or "Income" [Mesh] or "Poverty" [Mesh] or "Inequalities" or "Inequality", with each of the terms for tooth loss: "Tooth Loss" [Mesh] or "Loss, Tooth". Even thought this systematic review was aimed to assess the effect of income on tooth loss among adult subjects, we did not restrict the selection of studies on adults at this stage of the review.

All titles of the searches and abstracts of the papers that satisfied the eligibility criteria described below were assessed. After an initial screening, lists of selected papers were compared and in the case of disagreements, decisions were made following discussion based on the inclusion and exclusion criteria described below. The selected literature was independently reviewed by two authors and classified as suitable or not to be included in this systematic review. The full text of the papers considered by title and abstract to be pertinent for this review was then read. Later, additional publications were screened by the same two authors using a hand search of the reference lists of the studies that were found to be relevant in the previous step. Cases of disagreement between authors were discussed until a consensus was reached. Predefined data-collection worksheets were employed for the assessment of each selected publication.

2.1.2. Inclusion and exclusion criteria

Studies were included if they reported the relationship between income and tooth loss (clinical examination or self-reported) among adults aged from 18 to 60-years-old. Manuscripts published in English, Portuguese or Spanish were eligible for inclusion. All types of study design were included. Reviews, letters to the editor, abstracts from conferences were not considered.

2.1.3. Data extraction

Data were independently extracted by same two authors, using a standardized worksheet containing the following information: author, year of publication, geographic location (treated as a dichotomous variable—low/middle income; high-income countries), study design (cross-sectional, longitudinal), age of enrolled population, sample size ($\leq$1,000; >1,000), outcome definition (mean/median number of teeth lost; functional dentition; more than 15 teeth lost), main exposures definition (income), cut-of points of outcome and exposures, crude effect size with 95%CI, adjusted effect size with 95%CI, and type of adjustment. Only articles presenting crude and/or adjusted effect size measure with theirs respective 95%CI for income were eligible to be included in the meta-analysis. Authors were contacted in order to clarify any queries on the study methodology or result.

2.1.4. Qualitative evaluation of selected studies

All articles were classified according to an adaptation of the Downs and Black scale [15]. From the 27 original items in the checklist, 17 were employed, according to the modification performed by Wehrmeister and coworkers [16]. In essence, the authors did not consider the items that were specific for interventional studies. More information regarding the evaluated items can be found in Fig. 1. Each item scored one point, except for one item that could result at most two points. The total scoring could therefore range from 0 to 18 points. Articles were classifies as follows: high chance of bias (0–5 points), moderate chance of bias (6–11 points) and low chance of bias (12–18 points). Two referees evaluated selected papers independently and disagreements were decided by consensus after a discussion.

2.1.5. Statistical analysis

Different meta-analyses were conducted considering: (1) crude association between income and tooth loss; (2) adjusted association between income and tooth loss. When different categories of income were present, only the estimate comparing the most extreme categories was considered for meta-analysis. In case of time-series, just the most recent result was considered. When Prevalence Ratio was the association measure presented in the article, the one was converted into Odds Ratio using the formula proposed by Zhang and Yu [17]. For each model, a pooled effect was obtained using both fixed- and random-effects models. Heterogeneity among studies was evaluated using I^2 test. If heterogeneity was statistically significant ($P < 0.05$), a random-effects model was used. When heterogeneity was present ($I^2 > 50\%$), meta-regression was also performed to evaluate the contribution of study characteristics to the between-study variability [18]. Study characteristics were included as covariates in the meta-regression analysis, one at a time, rather than using an overall score of study quality. This approach allows the identification of aspects of study design that are potential sources of heterogeneity. All analyses were performed using the software STATA 12.0 (StataCorp., College Station, TX, USA).

1. Is the hypothesis/aim/objective of the study clearly described?
2. Are the main outcomes to be measured clearly described in the Introduction or Methods section?
3. Are the characteristics of the patients included in the study described clearly?
4. Are the distributions of principal confounders in each group of subjects to be compared described clearly?
5. Are the main findings of the study described clearly?
6. Does the study provide estimates of the random variability in the data for the main outcomes?
7. Have the characteristics of patients lost to follow-up been described?
8. Have actual probability values been reported (for example, 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?
9. Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
10. If any of the results of the study were based on 'data dredging', was this made clear?
11. Were the statistical tests used to assess the main outcomes appropriate?
12. Were the main outcome measures used accurate (valid and reliable)?
13. Were the patients in different groups recruited from the same population?
14. Were study subjects recruited over the same period of time?
15. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?
16. Were losses of patients to follow-up taken into account?
17. Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?

Fig. 1. Modified version of Downs and Black scale.

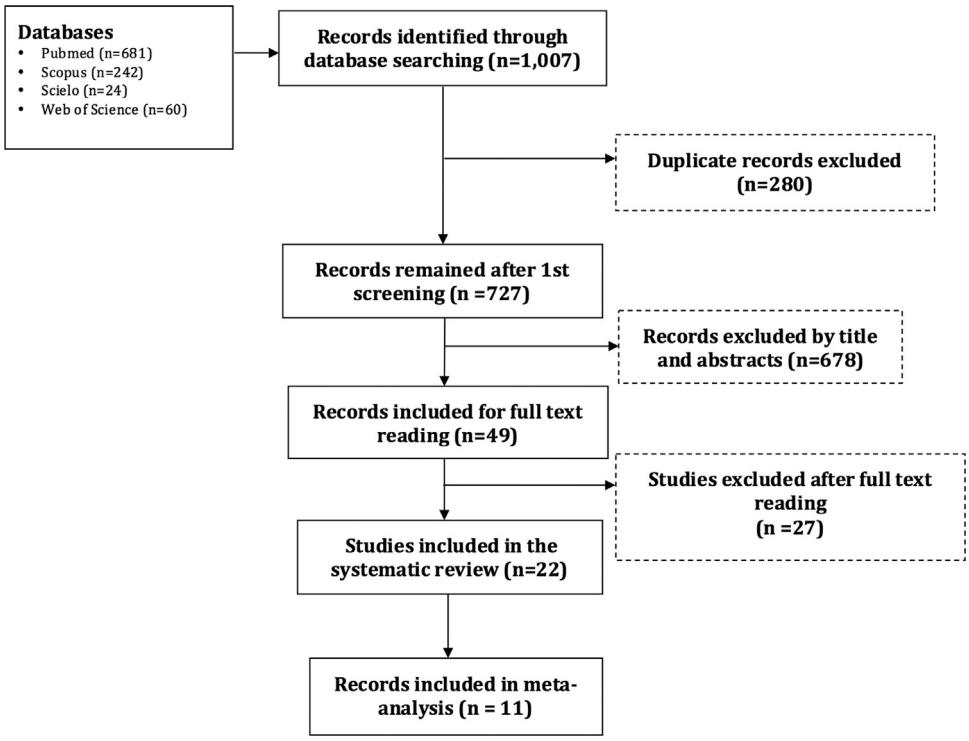

Fig. 2. Flow diagram of identification and selection process of studies.

3. Results

The electronic search identified 1,007 articles. From this total, 278 papers were duplicated, and excluded, remaining 729 studies. Fig. 2 shows the number of studies that remained in each step of search. We identified 49 potential manuscripts and 27 were excluded at this final stage (Fig. 2). Table 1 brings information of main reasons for exclusion.

Therefore, 22 articles were eligible for the systematic review, however, from those, only 11 presented data for meta-analysis, and were then, included. Table S1 (Supplementary material) displays the main characteristics of those studies that were selected in the review but not included in the statistical analysis ($n = 11$). Table 2 describes the main characteristics of the studies included in the meta-analysis ($n = 11$). According to Downs and Black checklist, all 11 papers included scored >12, revealing a low chance of bias.

Table 1
Excluded articles and main reason for exclusion.

Study	Year	Country	Reason for exclusion
Aida et al. [27]	2009	Japan	Elderly population only
Anderson et al. [28]	1974	Canada	Data stratified by gender
Ahlqwist et al. [29]	1991	Sweden	SEP assessed by occupation and educational level
Bernabé et al. [30]	2012	Finland	SEP assessed by a combination of income and education
Brown et al. [31]	1988	United States of America	The article could not be assessed
Cimões et al. [32]	2007	Brazil	No information about income and education associations
Celeste et al. [33]	2011	Brazil	SEP assessed by a combination of income and education
Frazão et al. [34]	2003	Brazil	SEP data organized by clusters
Gilbert et al. [35]	1999	USA	No effect size with income as an exposition
Hescot [36]	1997	Norway	SEP assessed by occupation
Holst and Shuller [37]	2012	Norway	There is no information about the outcome (tooth loss)
Jagger et al. [38]	2013	Scotland	Relationship with inequalities measure, without quantifying a direct effect of the exposure
Jimenez et al. [39]	2009	United States of America	SEP assessed by a combination of income and education
Medina-Solís et al. [40]	2008	Mexico	No information about income and education associations
Moreira et al. [41]	2010	Brazil	SEP assessed by educational level
Mundt et al. [42]	2007	Germany	Same sample from a previous study included in this review
Pearce et al. [43]	2009	United Kingdom	SEP assessed by occupation
Pihlgren et al. [44]	2011	Sweden	The article could not be assessed
Rihs et al. [45]	2009	Brazil	No relationship with SEP
Roder [46]	1975	Australia	No information about income and education associations
Shammery et al. [47]	1998	Saudi Arabia	SEP assessed by condition of the house
Susin et al. [48]	2005	Brazil	SEP assessed by a combination of income and education
Susin et al. [49]	2006	Brazil	SEP assessed by a combination of income and education
Thomson et al. [24]	2000	New Zealand	SEP assessed by occupation
Thomson et al. [50]	2004	New Zealand	SEP assessed by occupation
Thomson [3]	2012	New Zealand	SEP assessed by occupation
Wennström et al. [51]	2013	Sweden	SEP assessed by a combination of income and education; sample composed only by women

Table 2
Main findings of studies included in the meta-analysis.

Author	Year	Country	Sample	Study design	Main exposure definition	Exposure cut-off point	Outcome definition	Outcome cut-off point	Effect size and crude association results with 95%CI	Effect size and adjusted association results with 95%CI	Adjustment	Observations
Barbato et al. [52]	2007	Brazil	13,431 subjects from 35 to 44yo	Cross-sectional with secondary data	Household income	Income: Dichotomized with the cut-point set as the median value.	Lost teeth for any reason	Dichotomized in 12 teeth lost or more; and in less than 12 teeth	Income: RP 1.65 (1.53–1.79).	Income: RP 1.41 (1.31–1.51).	Adjusted for geographic location, age, gender and skin color	–
Batista et al. [53]	2012	Brazil	386 subjects from 20 to 64-yo	Cross-sectional	Household income	Income: Median value (U$ 588.24).	No tooth lost; 1 or more tooth lost; 3 or more; more than 4	Median value (3)	No tooth lost versus 1 or more: Income (<588.24): RP 1.18 (1.05-1.33); 3 or more versus 4 or more: Income (<588.24): RP 1.58 (1.22–2.04).	3 or more versus 4 or more: Income (<588.24): RP 1.35 (1.07–1.70)	Adjusted for age, presence of dental biofilm, gingival bleeding and clinical attachment loss ≥4mm	–
Celeste et al. [33]	2011	Brazil and Sweden	Brazil 3344 from 35 to 44-yo in 1986; Sweden 1000 from 35 to 44-yo at each survey	Cross-sectional	Income level	Higher or lower income level. Income in Sweden: defined by a question based on an amount of money enough to survey in a crisis moment - those who could mange the situation were classified in the higher economic class; Income in Brazil: ≥2 Brazilian Minimum Wages (higher) or <2 Brazilian MW (lower).	Edentulism	Sweden: self-reported oral health data and 5 possible responses: 1—no teeth or mere remains; 2—dentures, whole or part; 3—own teeth but in bad condition, many missing; 4—own teeth but many fillings or bridgework; 5—own teeth in good condition, no or few fillings. The first two answers were considered edentulism. Brazil: Missed component of DMF-T = 32.	Results presented a comparison between higher and lower economic class. Sweden 1968: PR 2.58 (1.99–3.35); 1974 PR 2.82 (2.00–3.98); 1981 PR 3.68 (2.30–5.87); 1991 PR 2.89 (0.79–10.53); 2000 PR 2.70 (0.50–14.6). Brazil 1986 PR 1.67 (1.43–1.94)	–		Brazilian data of 2002 were not used because it was already published in a different paper included in this review.
Correa et al. [54]	2010	Brazil	720 subjects with 24-yo	Birth cohort	Household income at birth; household income when subjects were 15 and 23;	Household income at birth: Brazilian Minimum wages (<1; 1–3; 3.1–6; 6.1–10; >10) with a division in tertiles (2nd and 3rd–non-poor; 1st–poor); household income at ages 15 and 23: Continuous variables and divided in tertiles (2nd and 3rd–non-poor; 1st–poor)– Trajectory of income during life-course: never poor; always poor; poor at birth and non-poor in adulthood; non-poor	One or more teeth lost	–	Family income at birth: 1st tertile PR 1.39 (1.06–1.84); Family income at 15: 1st tertile PR 1.40 (1.07–1.85); Family income at 23: 1st tertile PR 1.33 (1.01–1.76); Family's socio-economic trajectory from birth to age 15: Non-poor–poor PR 1.37 (0.94–2.01); Poor-non-poor PR 1.43 (0.94–2.16); always poor PR 1.55 (1.10–2.19).	Family income at birth: 1st tertile PR 1.37 (1.01–1.86); Family income at 15: 1st tertile PR 1.22 (0.90–1.66); Family income at 23: 1st tertile PR 1.05 (0.78–1.43); Family's socio-economic trajectory from birth to age 15: Non-poor–poor PR 1.37 (0.93–2.02); Poor-non-poor PR 1.36 (0.87–2.12); always poor PR 1.56 (1.08–2.26).	Adjusted for gender, skin color, mother educational level, dental caries and oral hygiene instruction.	Household income at age 23 was included in the meta-analyses

						at birth and poor in adulthood.						
Gilbert et al. [55]	2003	USA	Baseline: 873 African-American and Caucasian subjects from 4-yo or older; After 48 months of follow-up: 687 subjects	Cohort study - 48 months of follow-up	Household income	Household income (relative to $20,000 annually)	Mean number of teeth lost	Different cut-off points were adopted considering the mean and SD of teeth lost according to the expositions variables: Household income less than U$20,000/ year 3.6 (3.5); more than U$20,000/year 2.8 (3.6).	Income: OR 2.64 (1.84, 3.79);	–		–
Haugejorden et al. [56]	2008	Norway	1,092 subjects from 25 to 79-yo	Cross-sectional - telephone	Household income	Income: High - ≥ 250 NOK/year (U$ 37,480); Low - <250 NOK/year.	Number of teeth lost for any reason	Less than 20 remained teeth; more than 20 remained teeth	Income: Low - OR 4.13 (2.53–6.76).	Income: Low - OR 2.8 (1.6–5.1).	Adjusted for smoking and dental appointment	–
Jiang et al. [57]	2013	USA	11,385 subjects 18-yo or older	Cross-sectional - telephone	Household income	Income: High - ≥$25,000; Low - <$25,000.	None, 1 to 5 teeth lost, 6 or more but not all, and all (edentulism).	–	–	6-31 teeth lost versus none: Income OR 1.63 (1.10–2.40).	Adjusted for smoking, obesity and dental appointment	–
Koltermann et al. [58]	2011	Brazil	10,407 subjects	Cross-sectional	Household income	Income: High -≥ R$ 801; Medium–R$ 280-R$ 80; Low–R$ 0.00-R$279 (BRL).	Less than 20 remained teeth; more than 20 remained teeth	Less than 20 remained teeth; more than 20 remained teeth	Income: Medium - OR 1.28 (1.16–1.42); High–OR 2.55 (2.23–2.90).	Income: Higher income versus lower: OR 1.54 (1.33–1.78).	Adjusted for gender	–
Peres et al. [59]	2013	Brazil	9,779 subjects from 35 to 44-yo	Cross-sectional	Household income	Income: from $ 500; $ 501 to $ 1500; $ 1500 to $ 4500; more than $ 4500 (BRL).	Lost teeth for any reason	Less than 20 remained teeth; more than 20 remained teeth	Income: 4500–1501 - PR 2.17 (1.04–4.52); 1500–501 - PR 3.63 (1.69–7.80); Less than 500 - PR 4.74 (2.20–10.17).	Income: $4,500–$1,501: PR 1.53 (0.80–2.97); $1,500-$501: PR 1.83 (0.93-3.62); Less than $500: PR 1.99 (1.01–3.93).	Adjusted for gender, skin color	–
Silva et al. [60]	2009	Brazil	1,612 subjects from 35 to 44-yo	Cross-sectional with a representative sample	Household income	Income: Dichotomized with the cut-point set as the median value.	Lost teeth for any reason	Less than 20 remained teeth; more than 20 remained teeth	Income: R$ 500 RP 1.19 (0.97–1.46).	Income: R$ 500 RP 1219 (1.08–1.54).		
Urzua el al. [61]	2012	Chile	1,088 subjects from 35 to 44-yo	Cross-sectional	Household income and individual income	Income: High - >U $570/month; Low - ≤U$570/month.	Lost teeth for any reason	Less than 20 remained teeth; more than 20 remained teeth	Household income: OR 2.28 (1.5–3.46); Individual income: OR 1.65 (1.15–2.38).	Household income: OR 1.94 (1.24–3.04); Individual income: OR 1.34 (0.89–2.0).	Adjusted for depression, diabetes and obesity	–

RL: Brazilian Reais; NOK: Norwegian Krone.

The meta-analysis considering the crude association between income and tooth loss revealed a pooled effect of OR 2.52 (95%CI 2.11–3.01) for those subjects from lower income level (Fig. 3). Heterogeneity was detected in this model (I^2 85.4%). Only 8 studies reported adjusted estimates for the effect of socioeconomic status and the pooled effect was OR 1.66 (95%CI 1.48–1.86) in those subjects from the lower income level compared to those from the higher (Fig. 4). No heterogeneity was observed in this analysis (I^2 27.9%). Table 3 displays the subgroup and the meta-regression analyses. It is possible to observe that in the crude model, the sample size explained about 9% of the heterogeneity (Table 3).

4. Discussion

The results of this systematic-review and meta-analysis demonstrated a positive association between low income and tooth loss. To the best of authors' knowledge, this is the first systematic review with meta-analysis and meta-regression exploring such association. Even with previous individual results demonstrating this association, the pooled estimate obtained by a meta-analysis provides the most robust evidence, since the statistical power is highly increased. Additionally, the employment of a meta-regression analysis allowed us to identify possible sources of heterogeneity.

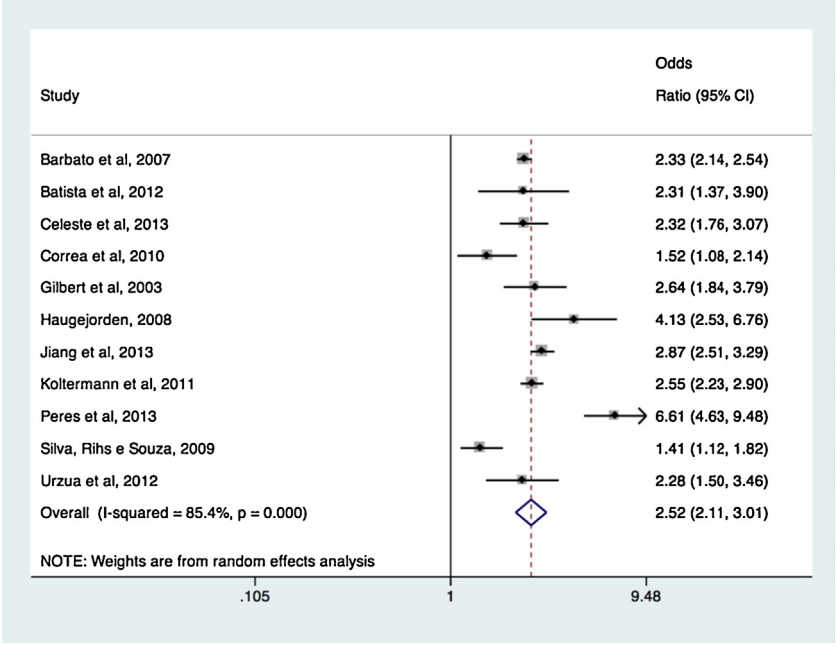

Fig. 3. Pooled effect of crude results of income on tooth loss.

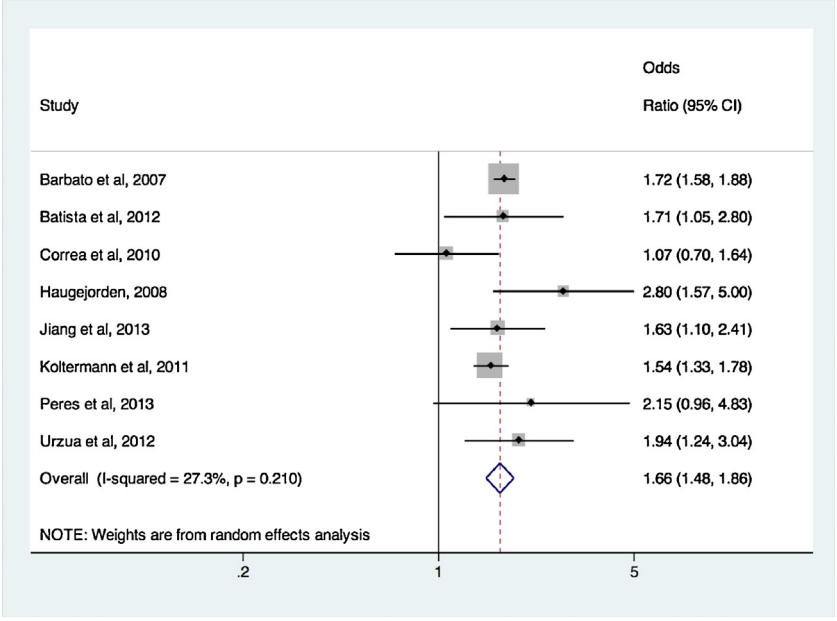

Fig. 4. Pooled effect of adjusted results of income on tooth loss.

Table 3
Income and tooth loss: Random-effects meta-analyses of tooth loss by subgroup and meta-regression analysis.

	Studies with crude results			
	Number of estimates	Pooled odds ratio and 95% confidence interval	*P*-value	% heterogeneity explained
Study design				0
Cross-sectional	10	2.64 (2.18–3.20)	<0.001	
Cohort	2	2.00 (1.16–3.43)	<0.001	
Sample Size				9.2
≤1,000	7	2.16 (1.57–2.97)	<0.001	
>1,001	5	2.89 (2.35–3.55)	<0.001	
Setting				0
High-income	4	2.79 (2.36–3.29)	<0.001	
Low/middle income	8	2.36 (1.83–3.04)	<0.001	
Categories of outcome				0
Mean/median number of lost teeth	3	2.07 (1.44–2.99)	<0.001	
Functional Dentition	6	2.90 (1.82–4.61)	<0.001	
More than 20 teeth lost	3	2.51 (2.15–2.94)	<0.001	
Year of publication				0
≤2009	4	2.33 (1.66–3.28)	<0.001	
>2010	8	2.65 (2.09–3.37)	<0.001	
Total	12	2.52 (2.11–3.00)	<0.001	–

The adverse effects of SEP, measured by income, in general health are also observed in oral diseases, once subjects living in poverty present worse systemic and oral health conditions. They concentrate greater prevalence of dental caries and periodontal diseases, main causes of tooth loss in adults [5,11,19], in a phenomenon known as “polarization” of disease [20,21]. Our results demonstrated that low income was associated with increased tooth loss, and the literature indicates possible explanations for that. First, income disparity could represent a disinvestment in public resources, such dental care services and water fluoridation, once the interests, needs and perceptions of the rich diverge from those of the poor. Thus, the damage of core public health measures to prevent oral diseases would have a direct effect on tooth loss. Second, the presence of income inequality may lead to a non-cohesive society, where diffusion of health information can be reduced. Besides that, income may affect tooth loss through “stress-induced oral-health-related behaviors” and psychological effects, since a relationship between those factors and tooth retention may exist [22]. Previous studies have demonstrated individuals in the lowest income level tend to present neglected health behaviors, which play a relevant role in the establishment and progression of dental caries and periodontal disease. Hence, influencing those factors will direct impact on tooth loss. In addition to those factors, it has been demonstrated that economic constraint is closely associated with the type of dental treatment delivered. While subjects in the lower income are more prone to dental extraction, those in the higher are more likely to seek for periodic routine appointments and conservative dental treatment, reflecting in a greater number of retained teeth [23,24]. It is worth pointing out that income may affect tooth retention by influencing the establishment of oral disease as a conjunction of all aforementioned reasons [25].

The reasons for not including some studies in the meta-analysis should be pointed out. Firstly, the statistical analysis used in some articles, such as linear regression, did not allow us to convert association measures in order to pool the estimates. Second, some studies used as the reference category those individuals with retained teeth, presenting the estimates as a protective factor. Including those articles would undermine the pooled estimates, once the association is presented in the opposite way. Finally, many studies presented only a bivariate analysis without an association measure, such as odds ratio. Those articles based their findings on the P-values of the tested association, which precluded their inclusion in our analytical approach. Although these studies were excluded from meta-analysis, they demonstrated results in the same direction of the included reports, reinforcing the strength of our findings.

In this study, it is relevant to distinct the concepts of income from socioeconomic inequality. The latter is a broad concept that comprises not only income but also professional status, education and social exclusion. In the field of economics, where these concepts are originated from, there is a common mistake when income inequality is a synonym of economic inequality. This difference is based on the multiple economic influences besides income that may affect individual advantages and substantial freedoms [26]. Nevertheless, and in the light of such limitations, the relevance of income as a socioeconomic measure cannot be questioned [1].

This review is not free of limitations. Firstly, most of included studies presented a cross-sectional design. This design precludes the establishment of a causal relationship, since the temporal association between presumed exposure and outcome cannot be determined. Secondly, subjects enrolled in included studies presented a large age range. However, in order to make this association more evident we chose to not include elderly in this review. As tooth loss is a common condition among the elders, we expected that the effects of income could not be adequately noted in this specific population, since most of the individuals experience some type of tooth loss, regardless of the socioeconomic position. Finally, our review used income as measure of socioeconomic position, and as aforementioned, it might have impacted on our findings. Other socioeconomic measures such as educational level and employment status should be considered for further reviews.

Regardless of the limitations, our study presents strengths that should be pondered. To the best of authors’ knowledge, this is the first systematic review with meta-analysis and meta-regression revealing the pooled association between income and tooth loss in adults. In addition, the number of individuals enrolled and the high quality of included studies provided strong evidence of our findings. These aspects compensate the low number of studies included in this review. Furthermore, the inclusion of studies from different settings suggests that the association between income and tooth loss is a global concern. Thus, our findings should not be restricted to specific scenarios.

This study provides useful data to evidence the positive association between low income and tooth loss. Our findings, however, suffer with the causal limitations of many cross-sectional

articles included in this review. Even though it is not possible to determine a causal relationship between exposure and outcome, this hypothesis cannot be refuted, since the association remained significant even in the adjusted model. In the light of our limitations, our results suggest a relationship between low income and tooth loss. Further investigations with longitudinal design and broader measures of socioeconomic position are encouraged in order to corroborate our findings.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jdent.2015.07.004.

References

[1] J. Lynch, G. Kaplan, Socioeconomic position, in: L.F. Berkman, I. Kawachi (Eds.), Social Epidemiology, Oxford University Press, New York, NY, 2003, pp. 13–35.
[2] J.M. Oakes, P.H. Rossi, The measurement of SES in health research: current practice and steps toward a new approach, Soc. Sci. Med. 56 (4) (2003) 769–784.
[3] W.M. Thomson, A. Sheiham, A.J. Spencer, Sociobehavioral aspects of periodontal disease, Periodontol 1 (2012) 54–63.
[4] C.J. Murray, T. Vos, R. Lozano, M. Naghavi, A.D. Flaxman, C. Michaud, et al., Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the global burden of disease study 2010, Lancet 380 (9859) (2012) 2197–2223.
[5] W.M. Thomson, Social inequality in oral health, Community Dent. Oral Epidemiol. 40 (2012) 28–32 Suppl 2.
[6] B. Rockhill, Theorizing about causes at the individual level while estimating effects at the population level: implications for prevention, Epidemiology 16 (1) (2005) 124–129.
[7] M.G. Marmot, Understanding social inequalities in health, Perspect. Biol. Med. 46 (3 Suppl) (2003) S9–23.
[8] W. Marcenes, N.J. Kassebaum, E. Bernabe, A. Flaxman, M. Naghavi, A. Lopez, et al., Global burden of oral conditions in 1990–2010: a systematic analysis, J. Dent. Res. 92 (7) (2013) 592–597.
[9] R.J. De Marchi, F.N. Hugo, J.B. Hilgert, D.M. Padilha, Number of teeth and its association with central obesity in older Southern Brazilians, Comm. Dent. Health 29 (1) (2012) 85–89.
[10] E. Musacchio, E. Perissinotto, P. Binotto, L. Sartori, F. Silva-Netto, S. Zambon, et al., Tooth loss in the elderly and its association with nutritional status, socio-economic and lifestyle factors, Acta Odontol. Scand. 65 (2) (2007) 78–86.
[11] M.A. Peres, G. Tsakos, P.R. Barbato, D.A. Silva, K.G. Peres, Tooth loss is associated with increased blood pressure in adults—a multidisciplinary population-based study, J. Clin. Periodontol. 39 (9) (2012) 824–833.
[12] R.G. Watt, G. Tsakos, C. de Oliveira, M. Hamer, Tooth loss and cardiovascular disease mortality risk—results from the Scottish Health Survey, PLoS One 0797 (2012) .
[13] A.E. Gerritsen, P.F. Allen, D.J. Witter, E.M. Bronkhorst, N.H. Creugers, Tooth loss and oral health-related quality of life: a systematic review and meta-analysis, Health Qual. Life Outcomes 8 (2010) 126.
[14] M. Furuta, Y. Yamashita, Oral health and swallowing problems, Curr. Phys. Med. Rehabil. Rep. 1 (2013) 216–222.
[15] S.H. Downs, N. Black, The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions, J. Epidemiol. Comm. Health 52 (6) (1998) 377–384.
[16] F.C. Wehrmeister, A.M. Menezes, L.C. Muniz, J. Martinez-Mesa, M.R. Domingues, B.L. Horta, Waist circumference and pulmonary function: a systematic review and meta-analysis, Syst. Rev. 1 (2012) 55.
[17] J. Zhang, K.F. Yu, What's the relative risk? A method of correcting the odds ratio in cohort studies of common outcomes, JAMA 280 (19) (1998) 1690–1691.
[18] C.S. Berkey, D.C. Hoaglin, F. Mosteller, G.A. Colditz, A random-effects regression model for meta-analysis, Stat. Med. 14 (4) (1995) 395–411.
[19] J.L. Antunes, P.C. Narvai, Z.J. Nugent, Measuring inequalities in the distribution of dental caries, Comm. Dent. Oral Epidemiol. 32 (1) (2004) 41–48.
[20] L.J. Oliveira, M.B. Correa, G.G. Nascimento, M.L. Goettems, S.B. Tarquinio, D.D. Torriani, et al., Inequalities in oral health: are schoolchildren receiving the Bolsa Familia more vulnerable? Rev. Saude Publica 47 (6) (2013) 1039–1047.
[21] M. Tickle, The 80:20 phenomenon: help or hindrance to planning caries prevention programmes? Comm. Dent. Health 19 (1) (2002) 39–42.
[22] E. Bernabe, R.G. Watt, A. Sheiham, A.L. Suominen-Taipale, A. Uutela, M.M. Vehkalahti, et al., Sense of coherence and oral health in dentate adults: findings from the Finnish Health 2000 survey, J. Clin. Periodontol. (11) (2010) 981–987 3.
[23] K.S. Klock, Patients' perceptions of the decision-making process leading to extraction of permanent teeth in Norway, Commun. Dent. Oral Epidemiol. 23 (3) (1995) 165–169.
[24] W.M. Thomson, R. Poulton, E. Kruger, D. Boyd, Socio-economic and behavioural risk factors for tooth loss from age 18 to 26 among participants in the Dunedin Multidisciplinary Health and Development Study, Caries Res. 34 (5) (2000) 3.
[25] E. Bernabe, W. Marcenes, Income inequality and tooth loss in the United States, J. Dent. Res. (2011) 724–729.
[26] A. Sen, Development as a Freedom, OxfordUniversity Press, Oxford, 1999107–108.
[27] J. Aida, T. Hanibuchi, M. Nakade, H. Hirai, K. Osaka, K. Kondo, The different effects of vertical social capital and horizontal social capital on dental status: a multilevel analysis, Soc. Sci. Med. 69 (4) (2009) 512–518.
[28] D.L. Anderson, G.W. Thompson, F. Popovich, Socioeconomic status, loss of teeth, and participation in a dental study, J. Public Health Dent. 34 (2) (1974) 106–112.
[29] M. Ahlqwist, C. Bengtsson, H.G. Grondahl, L. Lapidus, Social factors and tooth loss in a 12-year follow-up study of women in Gothenburg, Sweden, Comm. Dent. Oral Epidemiol. 19 (3) (1991) 141–146.
[30] E. Bernabe, R.G. Watt, A. Sheiham, A.L. Suominen, M.M. Vehkalahti, A. Nordblad, et al., Childhood socioeconomic position, adult sense of coherence and tooth retention, Comm. Dent. Oral Epidemiol. 40 (1) (2012) 46–52.
[31] L.J. Brown, L.H. Meskin, Sociodemographic differences in tooth loss patterns in U. S. employed adults and seniors, 1985–1986, Gerodontics 4 (6) (1988) 345–362.
[32] R. Cimoes, F. Caldas Junior Ade, E.H. Souza, E.S. Gusmao, Influence of social class on clinical reasons for tooth loss, Cien Saude Colet 12 (6) (2007) 1691–1696.
[33] R.K. Celeste, P. Nadanovsky, J. Fritzell, Trends in socioeconomic disparities in the utilization of dental care in Brazil and Sweden, Scand. J. Public Health 39 (6) (2011) 640–648.
[34] P. Frazão, J.L.F. Antunes, P.C. Narvai, Perda dentária precoce em adultos de 35 a 44 anos de idade: estado de São Paulo, Brasil, 1998, Revista Brasileira de Epidemiol. 6 (1) (2003) 49–57 1998.
[35] G.H. Gilbert, M.K. Miller, R.P. Duncan, M.L. Ringelberg, T.A. Dolan, U. Foerster, Tooth-specific and person-level predictors of 24-month tooth loss among older adults, Comm. Dent. Oral Epidemiol. 27 (5) (1999) 372–385.
[36] P. Hescot, D. Bourgeois, J. Doury, Oral health in 35–44 year old adults in France, Int. Dent. J. 47 (2) (1997) .
[37] D. Holst, A.A. Schuller, Oral health in a life-course: birth-cohorts from 1929 to 2006 in Norway, Comm. Dent. Health 29 (2) (2012) 134–143.
[38] D.C. Jagger, A. Sherriff, L.M. Macpherson, Measuring socio-economic inequalities in edentate Scottish adults—cross-sectional analyses using Scottish Health Surveys 1995–2008/09, Comm. Dent. Oral Epidemiol. 41 (6) (2013) 499–508.
[39] M. Jimenez, T. Dietrich, M.C. Shih, Y. Li, K.J. Joshipura, Racial/ethnic variations in associations between socioeconomic factors and tooth loss, Comm. Dent. Oral Epidemiol. 37 (3) (2009) 267–275.
[40] C.E. Medina-Solis, R. Perez-Nunez, G. Maupome, L. Avila-Burgos, A.P. Pontigo-Loyola, N. Patino-Marin, et al., National survey on edentulism and its geographic distribution, among Mexicans 18 years of age and older (with emphasis in WHO age groups), J. Oral Rehabil. 35 (4) (2008) 237–244.
[41] S. Moreira Rda, L.S. Nico, L.V. Barrozo, J.C. Pereira, Tooth loss in Brazilian middle-aged adults: multilevel effects, Acta Odontol. Scand. 68 (5) (2010) 269–277.
[42] T. Mundt, C. Schwahn, F. Mack, I. Polzer, S. Samietz, T. Kocher, et al., Risk indicators for missing teeth in working-age Pomeranians–an evaluation of high-risk populations, J. Public Health Dent. 67 (4) (2007) 243–249.
[43] M.S. Pearce, W.M. Thomson, A.W. Walls, J.G. Steele, Lifecourse socio-economic mobility and oral health in middle age, J. Dent Res. 88 (10) (2009) 938–941.
[44] K. Pihlgren, H. Forsberg, L. Sjodin, P. Lundgren, A. Wanman, Changes in tooth mortality between 1990 and 2002 among adults in Vasterbotten County, Sweden: influence of socioeconomic factors, general health, smoking, and dental care habits on tooth mortality, Swed. Dent. J. 35 (2) (2011) 77–88.
[45] L.B. Rihs, D.D. da Silva, L. de Sousa Mda, Dental caries and tooth loss in adults in a Brazilian southeastern state, J. Appl. Oral Sci. 17 (5) (2009) 392–396.
[46] D.M. Roder, Tooth loss in South Australia, Comm. Dent. Oral. Epidemiol. 3 (6) (1975) 283–287.
[47] A. al Shammery, M. el Backly, E.E. Guile, Permanent tooth loss among adults and children in Saudi Arabia, Comm. Dent. Health 15 (4) (1998) 277–280.
[48] C. Susin, R.V. Oppermann, O. Haugejorden, J.M. Albandar, Tooth loss and associated risk indicators in an adult urban population from south Brazil, Acta Odontol. Scand. 63 (2) (2005) 85–93.
[49] C. Susin, A.N. Haas, R.V. Opermann, J.M. Albandar, Tooth loss in a young population from south Brazil, J. Public Health Dent. 66 (2) (2006) 110–115.
[50] W.M. Thomson, R. Poulton, B.J. Milne, A. Caspi, J.R. Broughton, K.M. Ayers, Socioeconomic inequalities in oral health in childhood and adulthood in a birth cohort, Comm. Dent. Oral Epidemiol. 32 (5) (2004) 345–353.
[51] A. Wennstrom, M. Ahlqwist, U. Stenman, C. Bjorkelund, M. Hakeberg, Trends in tooth loss in relation to socio-economic status among Swedish women, aged 38 and 50 years: repeated cross-sectional surveys 1968–2004, BMC Oral Health 13 (1) (2013) 63.
[52] P.R. Barbato, H.C. Muller Nagano, F.N. Zanchet, A.F. Boing, M.A. Peres, Tooth loss and associated socioeconomic, demographic, and dental-care factors in Brazilian adults: an analysis of the Brazilian Oral Health Survey, 2002–2003, Cad. Saude Publica 23 (8) (2007) 1803–1814.
[53] M.J. Batista, L.B. Rihs, L. Sousa Mda, Risk indicators for tooth loss in adult workers, Braz. Oral Res. 26 (5) (2012) 390–396.

[54] M.B. Correa, M.A. Peres, K.G. Peres, B.L. Horta, D.P. Gigante, F.F. Demarco, Life-course determinants of need for dental prostheses at age 24, J. Dent. Res. (7) (2010) 733–738.
[55] G.H. Gilbert, R.P. Duncan, B.J. Shelton, Social determinants of tooth loss, Health Serv. Res. 38 (2003) 1843–1862 6 Pt 2.
[56] O. Haugejorden, K.S. Klock, A.N. Astrom, E. Skaret, T.A. Trovik, Socio-economic inequality in the self-reported number of natural teeth among Norwegian adults–an analytical study, Comm. Dent. Oral Epidemiol. 36 (3) (2008) 269–278.
[57] Y. Jiang, C.A. Okoro, J. Oh, D.L. Fuller, Sociodemographic and health-related risk factors associated with tooth loss among adults in Rhode Island, Prev. Chronic Dis. 10 (2013) E45.
[58] A.P. Koltermann, J.M. Giordani, M.P. Pattussi, The association between individual and contextual factors and functional dentition status among adults in Rio Grande do Sul State, Brazil: a multilevel study, Cad Saude Publica 27 (1) (2011) 173–182.
[59] M.A. Peres, P.R. Barbato, S.C. Reis, C.H. Freitas, J.L. Antunes, Tooth loss in Brazil: analysis of the 2010 Brazilian Oral Health Survey, Rev. Saude Publica 47 (Suppl 3) (2013) 78–89.
[60] D.D. Silva, L.B. Rihs, L. Sousa Mda, Factors associated with maintenance of teeth in adults in the State of Sao Paulo, Brazil, Cad Saude Publica 25 (11) (2009) 2407–2418.
[61] I. Urzua, C. Mendoza, O. Arteaga, G. Rodriguez, R. Cabello, S. Faleiros, et al., Dental caries prevalence and tooth loss in chilean adult population: first national dental examination survey, Int. J. Dent. 2012 (2012) 810170.