Acta Odontologica Scandinavica, 2013; 71: 363–371

informa
healthcare

REVIEW ARTICLE

Tobacco and dental caries: A systematic review

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Abstract

Objective. Despite the abundance of evidence linking tobacco consumption to many oral conditions, no systematic review of the relationship with dental caries is available. The main aim of this systematic review was, therefore, to evaluate the effect of tobacco smoking on dental caries in adult smokers. ***Materials and methods.*** According to the PRISMA checklist, observational studies published from January 1991 to June 2011 were reviewed. The quality of evidence for each finding was rated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology. ***Results.*** Five studies, four related to dental caries and one on oral bacteria activity, were finally included in a qualitative analysis; they were all cross-sectional studies. As a result, the overall quality of evidence was poor, with two articles given a score of very low and three a score of low according to GRADE. ***Conclusions.*** Tobacco smoking was found to be associated with an increased risk of dental caries. However, the overall poor quality of studies produced no validation for such an association. Further, more extensive research on this topic and prospective studies are needed.

Key Words: *cariogenic agents, nicotine dependence, oral bacteria, smoking*

Introduction

Tobacco consumption remains one of the leading causes of diseases. Six million tobacco-related deaths and an incalculable burden on the budget of health systems worldwide are the main figures when it comes to the consequences of smoking [1]. A trend of this kind seriously compromises health systems in many countries. Tobacco-related issue was eventually described as 'a public health nightmare' in *The Lancet* [2]. However, large tobacco corporations can still interfere with the World Health Organization's Framework Convention on Tobacco Control [3]. In this setting, the World Health Organization (WHO) selected 'tobacco industry interference' as the theme for the 2012 World No Tobacco Day, highlighting the aggressiveness of industries attempting to undermine public health [4].

Apart from being one of the major risk factors for general health, tobacco consumption is also a threat to oral health. More then 400,000 cases of oral cancer were diagnosed worldwide in 2002, with tobacco as the leading cause [5]. Apart from the clear relationship with periodontal diseases, tobacco was claimed to be part of the etiopathogenetic process of other oral health conditions, such as dental caries, mucositis, acute necrotizing ulcerative gingivitis, the healing process of oral mucosa, microflora and host response, as well as periodontal and implant-prosthetic treatments [5–7]. Despite an abundance of evidence linking tobacco consumption to periodontal disease, with a number of systematic reviews conducted on this topic [6,7], the relationship between tobacco consumption and dental caries remains less well investigated. No systematic review of this topic has been found.

In the second half of the 20th century, lifetime caries prevalence declined by up to 75% in many high-income countries [8]. Despite this, dental caries are present in both low- and high-income countries and still remain a major problem worldwide, affecting 60–90% of schoolchildren and almost all adults [9].

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(Received 14 March 2012; accepted 31 July 2012)

ISSN 0001-6357 print/ISSN 1502-3850 online
DOI: 10.3109/00016357.2012.734409

Dental caries is currently regarded as preventable and the frequent use of fluoride, regular oral hygiene and a reduction in the amount and frequency of sugar are known to be the most important recommendations [5]. However, the disease still impacts the quality-of-life of many individuals [10]. One person in four has been found to suffer from dental pain in the UK every year [5]. Moreover, a social trend describes huge inequalities in dental caries among countries and within countries. In the UK, the poorest 30% of the population uses only 0.037 days of household expenditure in order to purchase the annual average dose of the lowest cost toothpaste, while in Zambia 10.75 days are needed [11].

The hypothesis of this review was that tobacco is involved in the dental caries process as a risk factor. The aim was to evaluate the effect of tobacco smoking on dental caries in adult smokers and secondly to assess a related gender difference.

Materials and methods

The protocol used for this systematic review was the PRISMA 2009 checklist, which is available at www.prisma-statement.org [12].

Eligibility criteria

The included studies were observational *in vivo* studies (i.e. cohort studies, case-control studies and cross-sectional studies) assessing the association between tobacco smoking and dental caries in adults (>18 years of age) and considering subjects without any stated medical condition. Only studies in English were considered, due to the virtual absence of research published in other languages as a result of preliminary electronic database searches. The studies had to meet the following inclusion criteria:

- Described incidence and severity of dental caries in tobacco smokers (including any form of smoking, e.g. cigarette, pipe, water pipe);
- Dental caries registered as DMFT and/or DMFS, according to WHO standards [13];
- At least 1 year of smoking; and
- Clearly described objective, methods and results, with no significant discrepancies.

Case reports, case series, outbreak investigations and abstracts were excluded, as well as studies reporting no tobacco smoking or other tobacco consumption habits.

Possible outcomes for the included studies were:

- Increased incidence and/or severity of dental caries between smokers and non-smokers;
- Increased incidence and/or severity of dental caries between female and male smokers;
- No difference in incidence and/or severity of dental caries between smokers and non-smokers; and
- No difference in the incidence and/or severity of dental caries between female and male smokers.

Salivary secretion rates were considered when available and rate measurements were not exclusive criteria for inclusion.

Information sources and literature search

The following electronic databases were searched: Medline, Embase, The Cochrane Library and Google Scholar. Two preliminary searches were conducted in August 2011 in order to obtain an overall idea of findings and to polish search terms (MeSH words) and limits. The MeSH Browser [14] was accessed to identify entry terms and compose the final Boolean search. Only studies published between January 1991 and June 2011 were included. No related topic or relevant finding resulted from The Cochrane Library and Google Scholar and these electronic databases were therefore excluded from the final Boolean search. The final search was made in September 2011. Appendix 1 describes the limits for the electronic search. No clinical trials were expected to be found, due to the ethically unacceptable idea that any research would regard tobacco consumption as an intervention and they were, therefore, excluded (or not found). Abstracts were collected for all findings.

Study selection and data collection

The main reviewer (G.B.) screened all the collected abstracts and the registered title, author and whole reference in two separate files (one for included abstracts and one for excluded abstracts) using a screening guide based on eligibility criteria. The reason for exclusion was registered (Appendix 2). A new independent screening was conducted after 15 days (G.B.). Duplicates from different electronic databases were excluded. The full text of all studies judged as being potentially eligible in at least one screening was retrieved. The main reviewer then evaluated the full text for inclusion using a screening guide and a second reviewer (G.C.) screened all the findings. When disagreement occurred, a third reviewer (P.L.) was consulted. Reference lists of the included papers were reviewed and potential eligible studies were retrieved for full text evaluation.

Data items and risk of bias

The main reviewer used the STROBE Statement—checklist of items that should be included in reports of observational studies [15] in order to extract data. The second reviewer then screened the data extraction. When disagreement occurred, the third independent reviewer was consulted. The data were classified according to the study design (as criteria for matching samples), setting (as relevant information to

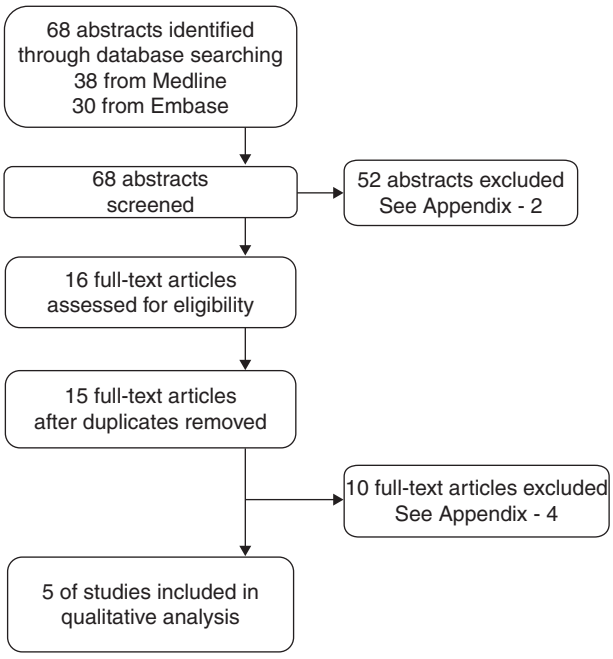

Figure 1. Flow chart of the study.

detect possible bias), funding (as a clue to a possible conflict of interest), population (as sources and methods for selection of participants), all variables taken into account (as possible confounders), methodological features (as methods for measurement), exposures (as qualitative and quantitative indicators), efforts to avoid exposure bias, statistical tools, outcomes (as punctual or follow-up results) and drop-outs. The presence of standardized instruments to measure smoking patterns was assessed. When other smoking habits were reported alongside tobacco smoking, the results of analyses were restricted to tobacco smokers alone. Measures derived from the regression models that adjusted for the maximum number of covariates were recorded.

The overall quality of evidence for each outcome was rated using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach (Appendix 3) [16].

Summary measures

Odd ratios (ORs) were selected according to the maximum number of confounders adjusted, the analysis of different forms of tobacco consumption or smoking. Linear associations and multiple regression models were taken into account.

Results

Figure 1 describes the study flow chart. The database search revealed 68 studies as being potentially eligible. After the abstract review, 52 were excluded (Appendix 2) and 15 were retrieved as full text and assessed for eligibility (after duplicate removal). Ten studies [17–26] were subsequently excluded as the eligibility criteria were not respected; see Appendix 4 for reasons for exclusion. No additional study was identified by checking reference lists of retrieved studies and this reference list check highlighted a large number of duplicates with database search results.

Finally, five studies of dental caries ($n = 4$) [27–30] and oral bacteria ($n = 1$) [31] were included in the qualitative analysis. One of the included studies also described a relationship between tobacco smoking and salivary secretion rate. All the studies were cross-sectional. Table I describes the characteristics of the included studies assessing the effect of tobacco smoking on different outcomes.

Dental caries

Two studies referred to sub-groups of a population: the Italian Military Academy and professional truck and bus drivers in Mexico [27,29]. The other two described tobacco effects in wider populations: the Rakai District in south-western Uganda [28] and the County of Värmland in Sweden [30]. The participants in all the studies were adult volunteers. The authors reported randomization for the included participants with one exception [27]. Two studies reported on cigarette smoking [27,29], while the others focused on tobacco smoking generally [28,30]. The measurement tool for tobacco consumption habits was always a questionnaire; the authors scarcely reported on the development and pre-testing of the questionnaire, with one exception [27]. The methods for measuring exposure levels differed in terms of quality (cigarettes/day, years of smoking, times of smoking/day, smoking yes/no) and quantity (no constant criteria were found). Measurements of the DMFT index were always reported and described as in WHO statements, even if different publications reported different methods. No study reported any blinding outcome methodology.

The authors described a constant association between tobacco smoking and an increased risk of developing dental caries between smokers and non-smokers. Aguilar-Zinser et al. [29] reported an association between the number of packs of cigarettes/year and caries severity (multiple linear regression model; $p < 0.01$) and found the strongest association for packs of cigarettes/year with the M component of the DMFT index (multiple linear regression model; $p < 0.01$). Campus et al. [27] described an increased risk of caries experience in heavy tobacco smokers when compared with non-smokers/light smokers (OR = 1.88, 95% CI = 1.3–2.7). Axelsson et al. [30] described four different age groups (35, 50, 65 and 75 years of age) and found that smokers (compared with non-smokers) had a larger number of missing surfaces in the 50-, 65- and 75-year age

Table I. Characteristics of included studies assessing the effect of tobacco smoking on dental caries, oral cariogenic bacteria and salivary secretion rate

Study	Exposure	Outcomes	Method features	Results
Campus et al. [27] Study design: cross-sectional Funding: not reported Setting and period: Italian Military Academy, Academy facilities in Genoa, Italy; September 2008 Population: 763 adult volunteers (722 men, 41 women); mean age 24.7 years (SD: ± 3.8)	Type: cigarette smoking Measurement tool: simplified structured self-compiled questionnaire submitted to participants before the clinical examinations; pre-tested questionnaire for control of reliability and validity; number of cigarettes per day (>10 cigarettes/day), years of smoking (smoking habits >3 years – yes/no) Exposure level of included subject: 126 non-smokers and 200 light smokers (<10 cigarettes/day and <3 years of smoking habit); 436 heavy smokers (>10 cigarettes/day and >3 years of smoking habit – reference group) according to WHO criteria (Strong and Bonita 2003[a]); 121 heavy smokers started ≥4 years before	Dental caries Measurement tool: dental examination following the WHO planning, indices, diagnostic criteria and methodology recommendation (WHO, 1997[b])—DMFS, Sic index; 4 trained and calibrated dentists (0.9 k-value, 95% agreement); double observation of random 10% of the sample (0.8 k-value, 99% agreement) Blinding of outcome adjudicator: not reported	Selection bias: participants informed of the study aim Information bias: objective outcome evaluation – yes; standardized exposure measure – no Confounding: matching for age, gender, number of cigarettes/day, years in the Military Academy, educational level; adjusted for smoking habit ≥3 years Participation rate: 1 volunteer refused to declare his/her smoking status	OR compared with non-smokers/light smokers: 1.88 (95% CI = 1.3–2.7)
Rwenyonyi et al. [28] Study design: cross-sectional Funding: Sida/SAREC financially supported the study Setting and period: Kyalurangira, Kabira and Kacheera sub-counties (randomly selected), Rakai District, south-western Uganda; period not reported Population: 321 adult participants (169 males, 152 females); mean age 38.8 years (SD ±15.5); participants randomly (stratified systematic random sampling technique reported)	Type: tobacco smoking (not specified) Measurement tool: A structured questionnaire with closed-ended questions (local language translation); no standardization reported; consumption as times/day (once, twice or more than twice a day) Exposure level of included subjects: smoking tobacco (yes/no); among smokers, 67 >2 times/day, 22 twice/day and 7 once/day; 225 non-smokers	Dental caries Measurement tool: dental examination following WHO recommendation (WHO, 1997[c])—DMFT Index; 3 trained and calibrated dentists (0.9 k-value); double observation of random 10% of the sample (0.8 k-value, $p > 0.05$, paired t-test) Blinding of outcome adjudicator: not reported	Selection bias: participants informed of the study aim Information bias: objective outcome evaluation—yes; standardized exposure measure—no Confounding: tobacco smoking habits (as times per day and tobacco smoking habits); adjusted for age, gender, educational level, sugar intake, tooth cleaning, tooth cleaning device, previous dental visits Participation rate: not reported	Multiple linear regression analysis r^2 change adjusted for tobacco smoking: 0.025

Table I. (*Continued*).

Study	Exposure	Outcomes	Method features	Results
Aguilar-Zinser et al. [29] Study design: Cross-sectional Funding: General Direction of Preventive Medicine in Transportation, Ministry of Communication and Transportation, and the Department of Health Care, Metropolitan Autonomous University Xochimilco Setting and period: Secretaría de Comunicaciones y Transportes, Ministry of Communication and Transportation, Mexico City, Mexico; September 2004–August 2005 Population: 851 male professional truck/bus drivers of 21,342 drivers applying for license validation; random sampling frame from the Ministry of Communication and Transportation; $\alpha = 0.05$, $1-\beta = 0.8$	Type: cigarette smoking Measurement tool: questionnaire submitted to participants before the clinical examinations; no standardization reported; non-smokers (currently not in the past), former smokers (quit >1 year), current smokers (at the time or quit <1 year), age when tobacco use started, years of smoking, cigarettes/day, years since quitting Exposure level of included subject: 227 non-smokers, 195 former smokers, 402 smokers Statistically established the pack-years variable: number of cigarettes per day/20 multiplied by the number of years smoked	Dental caries Measurement tool: dental examination following WHO recommendation (WHO, 1997[b])—DMFT index plus Large Cavities, LC (lesions affecting more then half of any tooth surface and root tips) identification; 1 trained and standardized dentist (no standardization reported); double observation of random 10% of the sample (no randomization reported, 0.9 k-value) Blinding of outcome adjudicator: not reported	Selection bias: participants informed of the study aim Information bias: objective outcome evaluation—yes; standardized exposure measure—no Confounding: tobacco smoking habits (recently former smokers and current smokers), cigarettes and packs per year; adjusted for age and educational attainment Participation rate: 97%; 2 participants excluded as they were toothless	Comparison between non-smokers, current and former smokers: Decayed teeth, $p = 0.85$ Missing teeth, $p < 0.01$ Filled teeth, $p = 0.27$ DMFT, $p = 0.07$ Number of cigarettes smoked vs DMFT index, $p = 0.02$ Pack-years vs DMFT index, $p = 0.01$ Regression models for pack-years with: DMFT, $p = 0.04$ Decayed, $p = 0.64$ LC, $p = 0.01$ Missing, $p < 0.001$ Filled, $p = 0.52$
Axelsson et al. [30] Study design: Cross-sectional Funding: not reported Setting and period: County of Värmland, Sweden; period not reported Population: randomized stratified sample of 35-year-olds (155), 50-year-olds (510), 65-year-olds (310) and 75-year-olds (310) of 220,000 inhabitants in the county; volunteers from both urban and rural areas	Type: tobacco smoking (not specified) Measurement tool: questionnaire submitted to participants before the clinical examinations; no standardization reported; non-smokers and current smokers; former smokers excluded Exposure level of included subjects: 137 male smokers of 536 males, 121 female smokers of 557 females	Dental caries Measurement tool: dental examination following Axelsson and Lindhe (1978[d]) recommendation; radiographic examination—DMFT and DMFS indices; 4 teams of dental examiners, trained and calibrated (0.99 intra-class correlation coefficient) Blinding of outcome adjudicator: not reported Saliva secretion rate Measurement tool: the volume in ml of saliva sampled per minute and produced by paraffin chewing (in 50-, 65- and 75-year-old subjects); no calibration or standardization reported Blinding of outcome adjudicator: not reported	Selection bias: participants informed of the study aim Information bias: objective outcome evaluation—yes; standardized exposure measure—no Confounding: matching for gender, years of smoking, tobacco smoking habits, number of times/day, socio-economic variables Participation rate: 192 subjects failed to attend clinical examination	Difference in DMFT of smokers and non-smokers across age groups. Student's t test: 35 years old, $p = 0.002$ 50 years old, $p = 0.002$ 65 years old, $p = 0.13$ 75 years old, $p = 0.003$

Table I. (*Continued*).

Study	Exposure	Outcomes	Method features	Results
Sakki et al. [31] Study design: Cross-sectional Funding: not reported Setting and period: Oulu City, Finland; period not reported Population: 1012 55-year-old volunteer citizens invited for examination	Type: tobacco smoking (not specified) Measurement tool: questionnaire submitted to participants before the clinical examinations; no standardization reported; non-smokers and regular/occasional smokers Exposure level of included subjects: 575 non-smokers, 204 regular/occasional smokers	Saliva yeasts, lactobabilli and mutans streptococci counts Measurement tool: Oricult-N® test, Dentocult-LB® method and Dentocult-SM® strip (Orion Diagnostica, Espoo, Finland) for yeasts (growth or no growth), lactobacilli counts (<10 000 or >10 000 CFU/ml) and mutans streptococci counts (<100 000 or >100 000 CFU/ml), respectively; measures collected in unstimulated saliva and after chewing paraffin wax after 30 s; Dentobuff-strip® method (Orion Diagnostica) for buffering capacity after stimulation Blinding of outcome adjudicator: not reported	Selection bias: participants informed of the study aim Information bias: objective outcome evaluation—yes; standardized exposure measure—no Confounding: matching for gender, years of smoking, tobacco smoking habits, number of times/day, socio-economic variables Participation rate: 232 subjects failed to attend clinical examination	Regression models for smoking (yes) with: Lactobacilli, $p < 0.0001$ Mutans streptococci, $p = 0.035$ Yeasts, $p < 0.0001$

Exposure and outcome measurements as reported in the studies.
[a]Strong K, Bonita R. The SuRF Report 1. Surveillance of risk factors related to non-communicable diseases: Current status of global data. Geneva: World Health Organization; 2003.
[b]World Health Organization. Oral health surveys—basic methods, 4th edn. Geneva: World Health Organization; 1997.
[c]World Health Organization. Oral health surveys—basic methods, 3rd edn. Geneva: World Health Organization; 1997.
[d]Axelsson P, Lindhe J. Effect of controlled oral hygiene procedures on caries and periodontal disease in adults. J Clin Periodontol S 1978;133:151.

Table II. Quality of evidence of different studies according to GRADE framework.

Study	Factors lowering quality	Factors raising quality	Final rating
Campus et al. [27]	Limitation of design: sample not representative of the general population Inconsistency: gender related	Plausible confounding: self-administered questionnaire Magnitude of effect	Low
Rwenyonyi et al. [28]	Limitation of design: confounding for age, gender and smoking habits Inconsistency: gender related Indirectness: tobacco smoking (not specified)	None	Very low
Aguilar-Zinser et al. [29]	Limitation of design: sample not representative of the general population	Plausible confounding: self-administered questionnaire	Low
Axelsson et al. [30]	Limitation of design: confounding for smoking habits Indirectness: tobacco smoking (not specified)	Plausible confounding: self-administered questionnaire Magnitude of effect	Low
Sakki et al. [31]	Limitation of design: confounding for smoking habits Indirectness: tobacco smoking (not specified)	None	Very low

groups than in the 35-year age group ($p = 0.01$, $p < 0.01$, $p = 0.01$, respectively).

No data relating to gender difference and smoking habits were available.

Oral bacteria

Sakki et al. [31] described the relationship when it came to the effect of tobacco smoking on oral bacteria in adult volunteers (mean age: 55 years) in the city of Oulu in Finland. No randomization of the sample was reported. Laboratory tests were used for measurements of saliva yeasts, lactobacilli and mutans streptococci counts with and without saliva stimulation. The authors found a consistent association between tobacco smoking and increased counts of lactobacilli and saliva yeasts ($p < 0.0001$), but not with mutans streptococci.

Salivary secretion rate

Apart from dental caries, Axelsson et al. [30] described saliva secretion rates in four age groups (35, 50, 65 and 75 years of age). A statistically significant difference in secretion between male smokers and non-smokers was found ($p = 0.01$, 95% CI = 0.6–0.1). No statistically significant difference was found regarding gender.

Overall quality

The quality of evidence of the different studies according to the GRADE framework is described in Table II. The absence of blinding for the outcome adjudicator was not felt to be a factor that reduced the quality of the studies. This was due to their observational nature and the fact that blinding for questionnaire evaluation is not thought to be feasible in the logical process when patients answer a questionnaire and are referred for clinical examination. The overall quality of evidence of the analyzed studies was poor, with two obtaining scores of very low [28,31] and three obtaining scores of low [27,29,30], according to the GRADE framework.

Discussion

The hypothesis that tobacco is a risk factor for dental caries did not obtain sufficient proof. According to the available findings, tobacco smoking was found to be associated with an increased risk of dental caries experience. However, the overall poor quality of the studies provides no validation for such an association with dental caries severity, oral bacteria counts, salivary secretion rate and difference between male and female smokers.

This review focused solely on tobacco smoking for two reasons: tobacco smoking is the leading form of tobacco consumption worldwide—with 5711 billion individual cigarettes consumed in 2000 [5]—and it is therefore clearly representative of the problem. Moreover, different modes of consumption (e.g. tobacco chewing and snuff) can be associated with too many other socio-behavioral confounders in turn related to dental caries.

Only studies reporting adult consumption were considered. Usually, child or young age are associated with naturally higher saliva flow rates, with the saliva as a protective factor for dental caries. Equally, old age may be a confounder for such a relationship due to the naturally reduced saliva flow rates, so an interaction term should be evaluated. In any case, the literature on this topic is inconsistent, with studies showing a decline in salivary rate in smokers [32], in addition to opposite outcomes [33].

In all the studies, the participants were volunteers and knew the purpose of the investigation. Since smoking nowadays is frowned upon by public opinion, the volunteers could have cheated when answering a questionnaire and been prone to minimize their habits—especially in front of medical personnel—leading to

different, biased outcomes and blowing up the tobacco smoking relationship with dental caries.

While the studies provided an objective evaluation of the outcomes, no standardized exposure measurement was available. Iida et al. [22], when investigating the effect of tobacco smoke on the oral health of US women of childbearing age, proposed the detection of serum cotinine (a metabolite of nicotine) in addition to self-reported data on cigarette smoking. This study was excluded because under-age subjects were analyzed together with those aged >18 years.

Another limit of the available evidence is the populations that were included in the research. Two studies reported results for sub-groups which are not possible to generalize to the total population [27,29]. Rural populations that primarily survive on cattle rearing and subsistence crop farming [28] could be affected by many protective or risky socio-economic and behavioural factors in relation to dental caries, while a single Swedish county [30] can be reasonably expected to be exposed to many other and yet still specific factors related to the area. The same holds true for the last study relating tobacco smoking to oral bacteria in the city of Oulu in Finland [31]. Additional evidence and relevance could therefore only be obtained from studies with a more extensive design.

The difference in dental caries between smokers and non-smokers can be ascribed to a range of factors and evidence is still lacking when it comes to weighting the actual role of tobacco smoking. Smokers may have lifestyle habits that are able to modify their oral health status [34]. Potentially, socio-behavioral factors could contribute more than biological ones to this relationship; as a major risk factor for general and oral health tobacco consumption is strongly related to educational and economic factors, while socio-economic development has been widely associated with caries experience [5]. Moreover, socio-economic development is able to modify a certain behavior, such as the increasing consumption of fluoride toothpaste in western countries during the last 40 years. Tobacco can plausibly be associated with other risk factors, such as poor-quality dietary habits, low domestic oral self-care, rare professional care-seeking and low out-of-pocket expenditure for dental care.

Since the role of tobacco smoking is still uncertain when it comes to the development of dental caries, it cannot be assumed to be a major risk factor for this disease and therefore justify related community and clinical preventive strategies. Nevertheless, it is still necessary from a general and medical health perspective to pursue the cessation of tobacco use and dental personnel have an important role to play in this respect [1,3,4].

Dental caries is a long way from being regarded as a primary concern when it comes to quitting smoking. There are other dreadful health-related effects of tobacco consumption which are paramount and the lack of public health policies remains a serious concern.

Acknowledgments

This review was not financially funded, but it received scientific support from the University of Sassari, Dental Institute, Sassari, Italy, the WHO Collaborating Centre of Milan for Epidemiology and Community Dentistry, University of Milan, Milan, Italy, and the University of Gothenburg, Institute of Odontology, The Sahlgrenska Academy, Gothenburg, Sweden.

***Declaration of interest*:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Supplementary material available online

Appendices 1-4.