Prevalence of Dental Caries in Past European Populations: A Systematic Review

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Keywords

Anthropology · Bioarcheology · Epidemiology · Europe · Systematic review

Abstract

Objective: Within the fields of anthropology and osteoarcheology, human teeth have long been studied to understand the diet, habits, and diseases of past civilizations. However, no complete review has been published to collect and analyze the extensive available data on caries prevalence in European man (*Homo sapiens*) over time. **Method:** In this current study, the two databases, Scopus and Art, Design, and Architecture Collection, were searched using predefined search terms. The literature was systematically reviewed and assessed by two of the authors. **Results:** The findings include a significant nonlinear correlation with increasing caries prevalence in European populations from 9000 BC to 1850 AD, for both the number of carious teeth and the number of affected individuals. **Conclusion:** Despite the well-established collective belief that caries rates fluctuate between different locations and time and the general view that caries

rates have increased from prehistoric times and onwards, this is to our knowledge the first time this relationship has been proven based on published data.

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Introduction

The caries disease has affected *Homo sapiens* for as long as it has existed, resulting in the development of carious lesions in the teeth. Evidence of the disease has been found not only in *Homo sapiens*, as reviewed in the current study, but also in Neanderthals [Topić et al., 2012] and humanoids [Fuss et al., 2018], evidently accompanying humanity throughout evolution. In the field of archeology, and in particular bioarcheology, the study of human dentition and its pathologies has long been a subject of major interest and has therefore been extensively studied. Due to their low percentage of organic matter, human jaws and teeth remain well preserved post mortem, enabling these structures to provide important information

on human subsistence and mortality throughout history. The highly mineralized tooth and bony tissues can be studied, sometimes epochs after burial, in order to assess age, reconstruct dietary patterns, obtain an understanding of complex social and cultural shifts, and provide an insight into past civilizations [Forshaw, 2004]. More recently, ancient DNA extracted from the well-protected dental pulp tissues has been studied in order to understand migration patterns of populations, cultures, and goods. It is irrefutable that dental tissues possess great research potential and provide valuable accounts of prehistoric life even for times prior to the development of written language.

Dental caries involves complex pathological processes in the dental biofilm (often referred to as dental plaque), including a shift in ecology favoring the microbiological fermentation of dietary carbohydrates into acids [van Houte, 1994]. Acid production may lead to the net demineralization of dental hard tissues, resulting in the formation of carious lesions, which may develop into cavities in the teeth. The disease is as old as man, but its prevalence has varied over time and in different locations. Oral microbiota are not merely able to ferment sucrose, but other carbohydrates, such as fructose and starch, can also be utilized [Kashket et al., 1994; Lingström et al., 2000]. Since the process of dental caries is complex and, in addition to the local oral microbiota, includes intricate interactions between salivary, dietary, genetic, anatomic, and physiologic factors [Chapple et al., 2017], no simple explanatory model is readily available when contemplating caries frequencies in historic man.

Changes in caries frequency recorded in archeological human remains are commonly explained by variations in dietary factors [Larsen, 2002]. During the Neolithic revolution starting around 10,000–8000 BC, with transitions in many human cultures from hunting and gathering to agriculture, the literature has reported a change in caries occurrence with increasing rates [Wittwer-Backofen and Tomo, 2008]. This has been suggested by both studies of human remains [Wittwer-Backofen and Tomo, 2008] and studies of the ancient oral microbiota [Adler et al., 2003]. The increase in caries prevalence is commonly explained by the dietary changes, including preparation techniques and food-crop cultivation this transition involved [Larsen, 2002].

Another well-known shift in the caries burden in human beings occurred with the advancement of industrialization during the 19th century, introducing sugars and processed foodstuffs to the masses, leading to an increase in disease prevalence. Later, the implementation and gen-

eral adaptation of preventive strategies, such as fluoride dentifrices, as well as the development of and advances in dentistry, have led to improved dental health. No comprehensive systematic review of the literature on the caries prevalence in historic and prehistoric European man has been published, but one meta-analysis of caries prevalence and tooth loss before and after the 19th century in Europe has previously been published [Müller and Hussein, 2017], reporting a small to moderate shift in dental disease. In textbooks, more general and global anthropological overviews of the historical occurrence of dental caries have been published [Lanfranco and Eggers, 2012]. The aim of the current study was to review the literature and present a collected data series on caries prevalence in *Homo sapiens* populations in the past, as well as commenting on findings from a joint historical, osteological, archeological, and odontological perspective.

Methods

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [Moher et al., 2009]. The search strategy was reviewed for accuracy using the Peer Review of Electronic Search Strategies criteria [McGowan et al., 2016].

The search strategy was developed by the librarian authors (E.H., H.S.) in collaboration with the other authors. The search was deliberately broad in an effort to include all the relevant articles. One multi-disciplinary database – Scopus – and one archeology specific – Art, Design, and Architecture Collection – were used. The searches were conducted on 27 May 2020 using the following search concepts and their synonyms: caries, archeological remains, Europe. An additional search was performed on 20 June 2021, using the same search strategy. For the full search strategy, see Table 1. No restrictions were applied to years searched or language of publications. The searches resulted in 1,580 results and, after de-duplication, 1,493 references remained. The references were downloaded into the Rayyan web application for systematic reviews to facilitate the review process [Ouzzani et al., 2016].

Figure 1 shows the PRISMA flowchart of the study selection and inclusion process. The inclusion criteria were i) English as the publication language, ii) time of death of studied remains no later than 1850, iii) geographic area Europe (current region), iv) cohorts comprising at least 10 individuals, v) permanent dentition, vi) data presented for either carious teeth or individuals with carious lesions, and vii) manifest lesions. Articles not presenting types of teeth recorded, methodology for caries diagnostics, or the stage of recorded carious lesions were excluded from the study, as well as articles that did not present any numerical data. Since only the permanent dentition was studied, only articles presenting data for individuals over the age of 12 were included and mixed dentitions were excluded.

Authors C.B. and E.B. screened all the titles and abstracts independently, resulting in 161 articles from the original search and 10 articles from the updated search, which were included for eligibil-

Table 1. Search terms*a. Scopus search*

#4	#1 AND #2 AND #3
#3	TITLE-ABS-KEY (Andorra* OR Austria OR Austrian OR Balkan OR Belgium OR Belgian OR Albania* OR "Baltic States" OR Estonia* OR Latvia* OR Lithuania* OR Yugoslavia* OR Bosnia* OR Herzegovina* OR Bulgaria* OR Croatia* OR Czech OR Hungary OR Hungarian OR Kosovo OR Kosovar OR Macedonia* OR Moldova* OR Montenegro OR Montenegrin OR Poland OR Polish OR Romania* OR Serbia* OR Slovakia* OR Slovenia* OR France OR French OR Germany OR German OR Greece OR Greek OR Ireland OR Irish OR Italy OR Italian OR Liechtenstein* OR Luxembourg* OR Cyprus OR Cypriot OR Malta OR Maltese OR Monaco OR Monegasque OR Netherlands OR Dutch OR Portugal OR Portuguese OR "San Marino" OR Sammarinese OR Scandinavia* OR Denmark OR Danish OR Greenland* OR Finland OR Finnish OR Iceland* OR Norway OR Norwegian OR Svalbard OR Sweden OR Swedish OR Spain OR Spanish OR Switzerland OR Swiss OR "United Kingdom" OR British OR English OR "Channel Islands" OR England OR Ireland OR Irish OR Scotland OR Scottish OR Wales OR Welsh OR Gaelic OR Russia* OR Belarus* OR Ukraine OR Ukrainian OR Europe*)
#2	TITLE-ABS-KEY (centuries OR century OR medieval OR medieaval OR Viking OR vikings OR hunter-gatherer* OR "grave yard*" OR graveyard OR churchyard* OR "church yard" OR burial OR burials OR exhumed OR exhumation OR excavated OR bio-archaeolog* OR bioarchaeolog* OR Historic* OR history OR Paleolithic OR ancient OR paleontol* OR paleodontol* OR archaeol* OR grave OR graves OR cemetery OR cemeteries OR massgrave*)
#1	TITLE-ABS-KEY("oral health" OR "dental disease*" OR "dental pathology" OR "oral pathology" OR "Dental Caries" OR caries OR carious)

b. Art, design and architecture collection (proquest) search

#5	Limit Peer reviewed
#4	#1 AND #2 AND #3
#3	Andorra* OR Austria OR Austrian OR Balkan OR Belgium OR Belgian OR Albania* OR "Baltic States" OR Estonia* OR Latvia* OR Lithuania* OR Yugoslavia* OR Bosnia* OR Herzegovina* OR Bulgaria* OR Croatia* OR Czech OR Hungary OR Hungarian OR Kosovo OR Kosovar OR Macedonia* OR Moldova* OR Montenegro OR Montenegrin OR Poland OR Polish OR Romania* OR Serbia* OR Slovakia* OR Slovenia* OR France OR French OR Germany OR German OR Greece OR Greek OR Ireland OR Irish OR Italy OR Italian OR Liechtenstein* OR Luxembourg* OR Cyprus OR Cypriot OR Malta OR Maltese OR Monaco OR Monegasque OR Netherlands OR Dutch OR Portugal OR Portuguese OR "San Marino" OR Sammarinese OR Scandinavia* OR Denmark OR Danish OR Greenland* OR Finland OR Finnish OR Iceland* OR Norway OR Norwegian OR Svalbard OR Sweden OR Swedish OR Spain OR Spanish OR Switzerland OR Swiss OR "United Kingdom" OR British OR English OR "Channel Islands" OR England OR Ireland OR Irish OR Scotland OR Scottish OR Wales OR Welsh OR Gaelic OR Russia* OR Belarus* OR Ukraine OR Ukrainian OR Europe*
#2	Centuries OR century OR medieval OR medieaval OR Viking OR vikings OR hunter-gatherer* OR "grave yard" OR «grave yards» OR graveyard OR churchyard* OR "church yard" OR burial OR burials OR exhumed OR exhumation OR excavated OR bio-archaeolog* OR bioarchaeolog* OR Historic* OR h istory OR Paleolithic OR ancient OR paleontol* OR paleodontol* OR archaeol* OR grave OR graves OR cemetery OR cemeteries OR massgrave*
#1	"oral health" OR "dental disease" OR "dental diseases" OR "dental pathology" OR "oral pathology" OR "Dental Caries" OR caries OR carious

ity assessment in full text. An additional manual search based on the citations and references for included articles resulted in the identification of one additional relevant article. Before starting the screening, the authors calibrated their assessment by assessing 10 abstracts together. When either of the authors was unsure, the other one was consulted. In cases of disparity, a third party (P.L.) was consulted. For the full-text reading, both C.B. and E.B. read the manuscripts and decided on inclusion or exclusion and, in the event of uncertainty, P.L. was consulted. Data extraction (including country, time period, examination type, age at death, teeth studied, gender, number of individuals and teeth, and individuals and/or teeth with caries) and further data work including statistics were performed by C.B. and E.B. supported by P.L.

Risk of bias was generally regarded as low, since special attention was paid to the inclusion criteria and inclusion process. A formal assessment of risk of bias was not performed, due to the nature of the bioarcheological examinations. However, in Table 2, the included articles are presented with the extracted information, which gives a further insight into each included study and its limitations.

Statistical work was performed using SPSS (Statistical Package for the Social Science) software. Reported means were extracted from the articles. Analyses of correlations between caries prevalence and time, for both teeth and individuals, were performed using Spearman's rank correlation test (2-tailed) for each cohort and significance was set at 0.05*.

Fig. 1. PRISMA flowchart.

Results

The data search and exclusion process resulted in 71 articles published between 1968 and 2021, presenting a total of 90 cohorts. Table 2 summarizes the characterizations of included studies.

In order to visualize the results, cohorts were, as specified in present-day geography, arranged into four regions; the Baltic Sea countries including Denmark, Finland, Latvia, Lithuania, Poland, and Sweden ($n = 16$), North-western Europe including Ireland and the United Kingdom, comprising England, Scotland, and Wales ($n = 20$), South-western Europe including France, Spain, and Italy ($n = 25$), and South-eastern and Central Europe in-

cluding Austria, Bulgaria, Croatia, Czech Republic, Greece, Hungary, Serbia, Slovakia, and Ukraine ($n = 29$) (Fig. 2). Unfortunately, several countries were not represented in the data. The minimum and maximum caries prevalence for teeth varied between 2 and 59% and, for individuals, between 26 and 93% in the four geographic areas. The Baltic Sea and south-west regions had a numerically higher maximum value for carious teeth compared with the other two regions. No caries-free populations were found.

The time periods of populations in the included studies ranged from 9000 BC to 1850 AD. In data presentation, the cohorts were grouped as follows: before 2000 BC ($n = 11$), 2000 BC to year 0 ($n = 7$), 1–999 ($n = 29$),

Table 2. Included studies and their characteristics

First author/year	Country	Time period	Examination type	Age at death, yr or teeth studied	Gender	Total number of individuals	Total number of teeth	Individuals with caries, %	Teeth with caries, %
<i>a. Characteristics of included studies dated before 2000 BC</i>									
Beck et al. [2018]	Spain	2800–2100 cal BC	Clinical	13–61+	Mixed	17	485	–	9.0
	Spain	2800–2100 cal BC	Clinical	31–61+	Mixed	51	3,085	–	7.0
Frayer [2004]	Czech Republic/ Slovakia	5300–5260 BC	Clinical	Adults	Mixed	108	2,597	50.0	6.0
Formicola [1987]	Italy	4th millennium BC	Clinical	18+	Males	10	225	60	–
Garłowska [2001]	Poland	4300–4000 BC	Clinical	20+	Mixed	54	1,187	42.5	4.7
Karsten et al. [2015]	Ukraine	3951–2620 cal BC	Clinical	Permanent teeth	Mixed	35	231	31.4	9.5
Lillie [2008]	Czech Republic	10000–4500 BC	Clinical	18–50+	Mixed	59	1,219	46.9	3.3
Lunt [1974]	Scotland	3000–1800 BC	Clinical	6+, permanent teeth	Unknown	100	656	–	1.7
Masotti et al. [2019]	Italy	Approx. 3000 BC	Clinical	Permanent teeth	Mixed	At least 18	354	–	16.7
Radović and Stefanović [2013]	Serbia	Neolithic	Clinical	Permanent teeth	Mixed	32	500	–	1.7
Silvana et al. [1985]	Italy, Sicily	9030–9300 BC	Clinical	Young mature adults	Mixed	10	167	–	13.0
<i>b. Characteristics of included studies dated year 2000 BC–0</i>									
Gualandi [1992]	Italy	500–300 BC	Clinical	Adults	Mixed	71	1,201	–	11.9
Keenleyside [2008]	Greece/Bulgaria	5th–2nd centuries BC	Clinical	18–50+	Mixed	162	2,939	53.8	7.7
Lunt [1974]	Scotland	300 BC to 0	Clinical	Permanent teeth	Unknown	20	301	–	6.6
Michael and Manolis [2014]	Greece	7th century BC to 2nd century AD	Clinical	20–51+	Mixed	32	381	46.9	7.9
Michael et al. [2017]	Greece	900 BC to 400 AD	Clinical	20–51+	Mixed	46	727	–	6.1
Masotti et al. [2013]	Italy	600–300 BC	Clinical	Permanent teeth	Mixed	80	680	26.2	5.0
Šikanjić [2006]	Croatia	9th–10th century	Clinical	18–45+	Mixed	30	292	–	4.5
<i>c. Characteristics of included studies dated year 1–999</i>									
Arnold et al. [2007]	Ukraine	8th–10th century	Clinical	18–40	Unknown	14	Unknown	–	1.7
	Ukraine	8th–10th century	Clinical	18–40	Unknown	11	Unknown	–	4.2
Bennike [1994]	Denmark	800–1000	Clinical	20–55+	Mixed	31	456	29	4
	Denmark	800–1000	Clinical	20–55+	Mixed	39	621	–	4.2
Bertilsson et al. [2020]	Sweden	10th century	Clinical	20–55	Mixed	18	370	77.8	11.9
Bonsall [2014]	England	270–410	Clinical	18–50+	Mixed	Unknown	3,227	59.0	9.0
Chazel et al. [2005]	France	4th–10th century	Clinical	12–36+	Unknown	36	355	–	9.0

Table 2 (continued)

First author/year	Country	Time period	Examination type	Age at death, yr or teeth studied	Gender	Total number of individuals	Total number of teeth	Individuals with caries, %	Teeth with caries, %
Cucina et al. [2006]	Italy	2nd–3rd century	Clinical	Adults	Mixed	77	1,408	–	2.5
Djurić Srejić [2001]	Serbia	10th century	Clinical	Adults	Mixed	105	1,680	55.7	8.9
Fernandez-Martinez et al. [2020]	Spain	300–600	Clinical	18–41	Mixed	21	Unknown	42.9	18.8
Jilková et al. [2019]	Czech Republic	9th–10th century	Clinical	Adults	Mixed	91	Unknown	78.0	–
Liebe-Harkort [2012]	Sweden	0–260	Clinical	21–60+	Mixed	96	1,794	92.6	44.2
Lunt [1974]	Scotland	400–1000	Clinical	Permanent teeth	Unknown	64	1,041	–	4.3
	Scotland	800–1000	Clinical	Permanent teeth	Unknown	22	307	–	2.9
	Scotland	1200–1500	Clinical	Permanent teeth	Unknown	29	400	–	6.0
Manzi et al. [1999]	Italy	1st–3rd century	Clinical	20–50+	Mixed	64	872	35.9	4.0
	Italy	1st–3rd century	Clinical	20–50+	Mixed	50	942	52.0	6.1
	Italy	7th century	Clinical	20–50+	Mixed	48	912	70.8	12.6
Marin et al. [2005]	Croatia	10th–11th century	Clinical	13–46+	Unknown	74	923	50.0	9.5
Meinl et al. [2010]	Austria	700–800	Clinical	20–61+	Mixed	136	2,215	54.7	14.9
Midon et al. [2019]	France	7th–18th century	Clinical	15+	Mixed	37	Unknown	–	9.9
Novak [2015]	Ireland	5th–11th century	Clinical	18–50+	Mixed	167	3,233	–	3.0
Peko and Vodanović [2016]	Croatia	3rd–5th century	Clinical	15–45+	Mixed	100	2,041	53.5	–
Šlaus et al. [2011]	Croatia	3rd–6th century	Clinical	18–35+	Mixed	103	1,992	–	9.7
	Croatia	7th–11th century	Clinical	18–35+	Mixed	151	1,590	–	11.7
Swales [2019]	England	8th–12th century	Clinical	Adults	Mixed	248	5,618	39.0	4.3
Thornton [1991]	England	4th century	Clinical	Adults	Mixed	91	Unknown	70.0	14.0
Walter et al. [2016]	England	120–1539 AD	Clinical	13–36+	Mixed	371	Unknown	63.0	–
Yanko et al. [2021]	Ukraine	400	Clinical + radiographic	18+	Mixed	25	647	28.0	1.7
<i>d. Characteristics of included studies dated year 1000–1499</i>									
Adamić and Šlaus [2017]	Croatia	13th–16th century	Clinical	18+	Mixed	30	768	–	6.2
Esclassan et al. [2009]	France	12th–14th century	Clinical	20–30+	Mixed	58	1,395	–	18.6
Chazel et al. [2005]	France	11th–15th century	Clinical	12–36+	Unknown	107	1,183	–	–
Gawlikowska-Sroka et al. [2013]	Poland	12th–15th century	Clinical	22–55	Mixed	58	Unknown	54.0	–
Kerr et al. [1988]	Scotland	1300–1600	Clinical	6–45+ permanent teeth	Unknown	68	1,088	29.4	5.1
Kerr et al. [1990]	Scotland	13th–17th century	Clinical	6–45+ permanent teeth	Unknown	101	1,869	43.6	7.4
Lopez et al. [2012]	Spain	11th–15th century	Clinical	Adults and mature	Mixed	At least 19	1,012	–	4.7

Table 2 (continued)

First author/year	Country	Time period	Examination type	Age at death, yr or teeth studied	Gender	Total number of individuals	Total number of teeth	Individuals with caries, %	Teeth with caries, %
López-Morago et al. [2020]	Spain	1000–1400	Clinical	16–60	Mixed	60	961	50	5.4
Lucas et al. [2010]	France	11th–12th century	Clinical + radiographic	20+	Mixed	60	788	80.0	17.5
Lunt [1974]	Scotland	1200–1500	Clinical	Permanent teeth	Unknown	29	400	–	6.0
McKenzie et al. [2020]	Ireland	1200–1600	Clinical	Adults 18+	Mixed	356	6,238	37.6	5.5
Michael et al. [2017]	Greece	13th–14th century	Clinical	20–51+	Mixed	16	126	–	16.7
Olsson and Sagne [1976]	Sweden	1060–1160	Clinical	14–60+	Mixed	51	Unknown	43.8	4.2
	Sweden	1160–1200	Clinical	20–60+	Mainly men 10	10	Unknown	60.0	5.5
	Sweden	1200–1536	Clinical	14–60+	Mixed	36	Unknown	55.8	8.1
Šlaus et al. [1997]	Croatia	14th to 17th century	Clinical	15+	Mixed	68	420	–	9.4
Šlaus [2000]	Croatia	14th–18th century	Clinical	16–60+	Mixed	68	765	–	10.9
Šlaus et al. [2018]	Croatia	1100–1400	Clinical	18–36+	Mixed	112	2,131	–	17.1
Trombley [2019]	Italy	1300–1500	Clinical	18–50+	Mixed	75	1,534	–	20.0
Ubelaker and Pap [2008]	Hungary	11th century	Clinical	Permanent teeth	Mixed	Unknown	2,067	–	3.8
Watt et al. [1997]	Scotland	1240–1440	Clinical	Juvenile-elderly adults	Unknown	734	3,706	–	6.7
<i>e. Characteristics of included studies dated year 1500–1699</i>									
Adamić and Šlaus 2017	Croatia	15th–18th century	Clinical	18+	Mixed	30	678	–	6.3
Arcini et al. [2020]	Sweden	17th–19th century	Clinical	20–59	Mainly men 220	220	Unknown	37.0	–
Bertilsson et al. [2021]	Sweden	1500–1620	Clinical	Adults	Mixed	205	4,951	68.0	13.0
Bonsall and Pickard [2015]	England	1500	Clinical	18–50+	Mixed	200	2,037	55.5	8.1
Chazel et al. [2005]	France	16th–17th century	Clinical + radiographic	12–36+	Unknown	109	1,267	–	18.8
Giuffra et al. [2020]	Italy	1583	Clinical	Adults 18+/permanent teeth	Mixed	81	868	50.7	5.2
Lopez et al. [2012]	Spain	16th–18th century	Clinical	Adults and mature	Mixed	At least 77	1210	–	12.0
Lingström and Borrmann [1999]	Sweden	1621–1640	Clinical + radiographic	16–45+	Unknown	65	943	60.3	11.6
Miliauskienė and Jankauskas [2015]	Lithuania	16th–17th century	Clinical	Adults	Mixed	150	3,015	80.0	20.8
		16th–17th century	Clinical	Adults	Mixed	39	981	64.0	11.4
Petersone-Gordina et al. [2018]	Latvia	15th–17th century	Clinical	18–31+	Mixed	225	4,591	55.2	6.4
Šlaus et al. [2018]	Croatia	1400–1700	Clinical	18–36+	Mixed	161	2,655	–	14.0

Table 2 (continued)

First author/year	Country	Time period	Examination type	Age at death, yr or teeth studied	Gender	Total number of individuals	Total number of teeth	Individuals with caries, %	Teeth with caries, %
Smith [2019]	England	1570–1740	Clinical	18+	Mixed	224	5,191	87.0	14.3
Varrela [1991]	Finland	Late medieval to 1600	Clinical	17–45+	Mixed	288	3,697	54.1	–
Vilkama et al. [2016]	Finland	17th–18th century	Clinical	20+	Mixed	176	1,388	43.0	23.2
Wells [1968]	England	17th–19th century	Clinical	13+	Unknown	192	622	0	17.4
<i>f. Characteristics of included studies dated year 1700–1850</i>									
Geber and Murphy [2018]	Ireland	1847–1851	Clinical	18–46+	Mixed	363	6,860	79.9	19.4
Malčić et al. [2011]	Croatia	18th century	Clinical	15–45+	Mixed	104	1,610	74.4	18.4
Quade and Binder [2018]	Austria	1809	Clinical	14–45	Mixed	30	591	83.8	–
Seiler et al. [2017]	Italy, Sicily	18th–19th century	Clinical	Juvenile-elder	Mixed	111	Unknown	–	58.5
Ubelaker et al. [2009]	Spain	19th century	Clinical	18–90	Mixed	133	346	–	27.5
Whittaker and Molleson [1996]	England	18th century	Clinical + radiographic	17–55+	Mixed	66	1,576	94.0	13.1

1000–1499 ($n = 21$), 1500–1699 ($n = 16$) and 1700–1850 ($n = 6$). A large variation in caries prevalence was found within each time period (Fig. 3, 4). A steady increase in the number of both affected individuals and carious teeth was seen from prehistoric times to 1850.

Cohorts ranged from 10 to 734 individuals and the number of examined teeth ranged from 126 to 6,860. Information on the number of individuals in the studied cohort and the number of teeth examined was presented for the majority of the cohorts ($n = 89$, $n = 80$) and no cohort lacked information on both variables. The individuals' biological age at the time of death ranged from 13 to more than 60 years of age, although some articles merely stated that “adults” were studied, without any further specification regarding age, and others stated that permanent teeth had been studied, with no further declaration of age at the time of death. In 68 of the cohorts, the biological sex of the subjects was specified in the article. The majority of publications studied cohorts of mixed gender populations, but two publications included only male subjects [Lucas et al., 2010; Quade and Binder, 2018].

Already during Neolithic times, around 10% of teeth and almost half the individuals in included populations were affected by caries. The prevalence for both individuals and teeth was lower during the prehistoric and historic time periods than in the early modern period cohorts. A dramatic increase in caries prevalence could be seen during the early modern period, where up to 95% of individuals and 60% of teeth were affected. A significant positive nonlinear correlation was found between time and caries prevalence, for both individuals and teeth with caries (see Table 3).

Discussion

The findings in the current study indicate a general nonlinear increase in caries prevalence in Europe over time, from 9000 BC to 1850 AD, which correlates well with previous knowledge of the disease and its main risk factors [Selwitz et al., 2007]. This trend is explained by a successive increase in the access to and consumption of carbohydrates, which is related to the domestication of crops, the development of agriculture and the use of different food preparation processes. Around 10% of the teeth and almost half the individuals in the included cohorts already suffered from dental caries during Neolithic times. This relatively high occurrence of dental caries is explained by dietary changes following the transition from hunting and gathering to agriculture. The caries

Fig. 2. Caries prevalence in different geographical areas and number of cohorts per country and region.

prevalence increased during the Bronze Age, Iron Age, and Early Middle Ages, explained by the continuous domination and development of agriculture. During the late Middle Ages and early modern period, a dramatic increase in caries prevalence was seen, explained by the introduction of sucrose and other, for the oral microbiota, fermentable carbohydrates in the diet. This change,

with increasing rates of dental caries over time, confirms the previously assumed relationship between disease burden and chronological time.

The findings also included variations in caries prevalence within time periods and regions, which must be attributed and related to the circumstances of each cohort regarding nutrition, technology, societal context, socio-

Fig. 3. Manifest carious lesions in groups ordered by chronological time of death. The line indicates the median, the box the 25th and 75th percentiles, and the whiskers the 10th and 90th percentiles. The mean is shown as x and the line indicates the median.

Fig. 4. Number of teeth with manifest carious lesions in groups ordered by chronological time of death. The line indicates the median, the box the 25th and 75th percentiles, and the whiskers the 10th and 90th percentiles. The mean is shown as x and the line indicates the median. Dots indicate outliers.

Table 3. Statistical work

	Cohorts, <i>n</i>	Correlation coefficient	<i>p</i> value
Prevalence of teeth with manifest caries over time	80	0.425	<0.001
Prevalence of individuals with manifest caries over time	50	0.336	0.017

The correlation between time and caries prevalence for teeth and individuals, using Spearman's rank correlation test (two-tailed).

economics, genetics, geology, and geography. Unknown factors may also play a role in the caries development within these cohorts. Throughout history, Europe has shown large-scale heterogeneity regarding resources, culture, and populations, which probably influences the data, as well as time variations in societal and industrial development for the different cohorts. However, all these factors appear to be overridden by the time aspect reflected in the results of the current study. In the light of contemporary epidemiological data, it is interesting to consider that, in spite of an overall reduction in caries prevalence, large variations remain in modern man, both within and between countries [Kassebaum et al., 2015; Norderyd et al., 2015].

Variations in the collected data highlight the difficulty involved in predicting caries prevalence based merely on the geographic location or chronologic time, without considering the contextual differences in the studied population. However, in spite of the influence of multiple complex factors, a clear positive trend for dental caries can be seen in Europe from prehistoric times to the end of the industrial revolution.

Since research data within the field of archeology have traditionally been presented in a wide range of ways and a proportion of the studies are written in non-English languages, articles are commonly found in local journals rather than global databases. It is therefore probable that a number of cohorts were not identified in the literature search since they were not eligible for the search terms used in the current study. Importantly, many articles on the topic were published at a time when scientific standards for data collection and presentation were different and not comparable to current standards. Consequently, a number of articles detected in the original search were unfortunately excluded due to these shortcomings.

Possible uncertainties in analyzed data must be considered, such as examinations only being performed by a single individual and a fairly large proportion of examiners in the included studies not being dentists or spe-

cialists in odontology. The lack of radiographic imaging in the majority of the included articles is a probable source of bias, as it is well known that radiographic imaging can provide additional information on caries diagnostics, especially proximal lesions [Lucas et al., 2010]. In ancient human remains, teeth can rarely be associated with specific individuals due to fragmentation or damage, burial practices, and ground conditions, which creates uncertainty in the data. Several of the included studies presented data for only either teeth or individuals with caries but not both. It is also important to note that the wide range in the number of subjects and teeth reviewed in included articles, extending from 10 to over 700 individuals and 126 to more than 6,000 teeth, poses a limitation in the current study. Unfortunately, some geographic regions were not represented in the collected data and, in the current study, they must be regarded as terra incognita regarding the historical burden of dental caries. To provide a more comprehensive depiction, additional research is needed in several regions and time periods. Due to the nature of archeological methodology, bias assessment was not regarded as realistic in the present study.

Lost teeth were not considered in the current analysis, which can be regarded as a source of bias, since the lost teeth contain valuable information that cannot be considered [Hillson, 2001]. The etiology of tooth loss in archeological remains varies and is represented by both ante-mortem tooth loss, due to causes including dental caries, periodontology, trauma, extractions, and infections, and additionally tooth loss occurring post mortem. Because of the unclear etiology and the aim of this study only to study dental caries, this factor was not included in the current work but must be regarded as a potential source of error.

An additional risk of bias is the variation in biological age at death. In the current review, this factor has not been included simply because age determination is not precise enough in the majority of the included cohorts (see Table 2). Archeological age assessment is frequently based

on osteological analysis, which is more difficult for adults compared with younger individuals [Mays, 2015]. The risk of caries correlates with age, due to increased exposure to the oral environment and associated risk factors. Carious lesions should thus accumulate during the life span in populations without access to dental treatment [Hillson, 2001]. Since the life expectancy of *Homo sapiens* has fluctuated from prehistoric to modern times [Angel, 1969], but with a general increase in life expectancy during the modern period, it is tempting to draw the conclusion that the probability of finding carious lesions increases with time as well. However, the risk of tooth loss, both ante- and post mortem, also increases with increasing biological age at death [Durić et al., 2004]. It is also well known that life expectancy is related to a number of factors such as biological sex, socioeconomics, genetics, environment, and geography and is not linear through history. The relationship is therefore complex. Because of this, the current study has not included lost teeth and biological age at death in the analysis of the data, but future research should aim to include both factors, even though this would substantially limit the number of included cohorts.

In the future, the authors would like to highlight the importance of quality assurance in dental examinations of archeological remains, together with the need for an increase in the international accessibility of published data, as the large number of articles that had to be excluded from this study due to limitations in publication language, methodology, and/or data presentation is truly a lost opportunity. To improve the quality of published data, the authors suggest using systematic examination protocols, including (1) recordings of the age, number, distribution, biological sex, and age at death of the studied remains, as well as the number of studied teeth and lost teeth, (2) defining the stage of carious lesions examined, included and recorded, (3) using a caries index for recording and comparing the occurrence of dental caries, (4) utilizing radiographic imaging for diagnostics or at least for the reliability control of the clinical diagnostics, and (5) examiner standardization and calibration to improve intra- and inter-examiner reliability. These aspects have previously been highlighted in a study by Liebe-Harkort et al. [2010]. It must be remembered that the opportunity to study these fascinating historical populations, and thereby obtain an insight into sustenance and life and death in ancient times, becomes rarer as time passes.

Conclusions

To our knowledge, this is the first time an attempt has been made to summarize the occurrence of dental caries in Europe based on data from Neolithic times to 1850 AD. In spite of its limitations, the current study conclusively identifies a general trend towards increasing caries prevalence for both individuals and teeth in past European populations, from 9000 BC to 1850 AD. Increasing caries rates are mainly explained by dietary changes related to agriculture and industrialization, even though various other risk factors influencing and adversely affecting the oral microbiota and dental hard tissues must be considered when contemplating the historical caries burden of specific cohorts.

Statement of Ethics

An ethics statement is not applicable because this study is based exclusively on published literature.

Conflict of Interest Statement

The authors have no competing interests to report.

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Author Contributions

C.B. wrote the original draft, performed article analysis together with E.B., curated data, and conducted the formal statistical analysis. She was also responsible for visualization, together with E.B. and P.L. E.B. contributed to the analysis, writing, and curating of the data. S.S. contributed archeological expertise and participated in editing the manuscript. E.H. and H.S. performed the search and formulated the search terms together with C.B. and contributed to the writing of the manuscript. P.L. conceptualized the study, supported the analysis and data visualization, was the main supervisor, and participated in writing and editing the manuscript. All the authors have read and approved the final manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author in response to a reasonable request.

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