The scoring, interpretation and prevalence of dental pathology in a Dutch skeletal sample from the late 18th and early 19th century

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1. Introduction

A substantial restoration of the Broerenkerk, a late medieval church in the Dutch city of Zwolle, was conducted during the 1980s. This led to an archaeological excavation in the winter of 1987-88 because the construction of a sub-floor heating system would render inaccessible and partly destroy the archaeological and physical anthropological information contained within the church building, especially the human skeletons buried under its floor. Therefore the excavation had a twofold purpose: 1. to collect as many data as possible on the history of the church building and 2. to salvage at least part of the human skeletal material present under the church floor. The attractiveness of this second objective was enhanced by the availability of the church's burial register from the period 1819-28, i.e. the last ten years in which people were actually buried within the church. This provided the possibility of identifying 141 individuals as to their sex and 138 individuals as to their age at death. Information pertaining to the profession of the deceased was also provided by the church register in a number of cases. A study of the historical data indicated that the sample contained only a part of the town's population, i.e. the social middle class (Bouts et al. 1992a, 1993; Hagedoorn 1992; and vide Constandse-Westermann & Bouts in press).

The identified sub-sample enabled the investigators to test their anthropological methodology (Aten 1990, 1992; Bouts et al. 1992a, 1993; Constandse-Westermann 1997; d'Hollosy 1989; Stikker 1989). In addition to these 141 identified individuals, the Zwolle sample further contained 388 unidentified skeletons, of which the majority dates from the late 18th and the early 19th century AD. Unfortunately, the skeletons of this unidentified sub-sample could be investigated only partially before their re-burial. In this paper the dental pathology of the total skeletal sample will be presented.

2. The dental sample.

In Table 1 the composition of the dental sample is presented, which comprized 412 individuals, i.e. 77.9 % of the total skeletal material. No heterogeneity is observed between the compositions of the identified and unidentified sub-samples.

Table 2 presents the age distribution of the individuals in the dental sample, which is also homogeneous between the two sub-samples. Calendar ages were only available for those individuals which were identified by the church register. Therefore the second column of Table 2 is based upon the age estimations by dental development and eruption for the children and some of the adolescents and by dental attrition for the remaining adolescents and the adults. For the children and adolescents these estimations could be related to and therefore added to the calendar ages in column 1. For the adults this was not the case.[1] Therefore all adult ages used in this study are calibrated estimations. Our method of calibrating the age estimations by using the calendar ages of the individuals in the identified sub-sample has been described elsewhere (Bouts et al. 1992a, 1993; Constandse-Westermann 1997). It led to a significant improvement (58.8%, $\Sigma X^2 = 55.234$, d.f. = 1, $p < .001$ for the adult identified sub-sample) in the interpretation of the age classes based on dental attrition and alveolar resorption (Bouts et al. 1992a, 1993; Constandse-Westermann 1997).

The sex diagnoses for the individuals whose dentitions are presented here have been made by the evaluation of cranial and pelvic morphology and by the measurements of the capita humeri. In order not to obscure the results of our dental analyses we wished to be rather strict in our acceptance of the final sex assessments. The methodological investigations mentioned above (Aten 1990, 1992; d'Hollosy 1989; Stikker 1989) allowed us a considerable amount of control over these assessments. In our final evaluation we have accepted ambiguity in the result of not more than one of the diagnostic methods and we have not accepted any contradiction between them. This procedure resulted in a group of 102 males and 120 females in which dental pathology could be analyzed, taking sexual differentiation into account.

	CHILDREN AND ADOLESCENTS* ≤ 21 years			ADULTS > 21 years
	Deciduous dentitions	Exfoliating dentitions	Permanent dentitions	Permanent dentitions
Identified sub-sample	18	6	5	90
Unidentified sub-sample	36	7	6	244
Total	54	13	11	334

Fisher Multiple Contingency test (ident./unident.): $p = .350$

	TOTAL SUB-ADULTS	ADULTS
Identified sub-sample	29	90
Unidentified sub-sample	49	244
Total	78	334

Chi-Square Two-Sample test (ident./unident.):
Sum Chi-Square = 3.224, d.f. = 1, $.100 > p > .050$

Table 1. The composition of the dental sample from Zwolle.
*** Deciduous dentitions: no permanent elements in occlusion;**
Exfoliating dentitions: at least one permanent element in occlusion;
Permanent dentitions: all permanent anterior teeth and premolars in occlusion.

	IDENTIFIED SUB-SAMPLE	UNIDENTIFIED SUB-SAMPLE
Age classes	Calendar ages	Estimated ages
0- 1	10	14
1- 5	8	18
5-10	2	8
10-15	4	4
15-21	5	5
	Estimated ages	Estimated ages
22-30	7	18
25-50	22	50
45-70	27	72
>65	27	84
Total	112	273

Kolmogorov-Smirnov Two-Sample tests (ident./unident.):
Total distributions: N1 = 112, N2 = 273, $.300 > p > .200$;
Adolesc. + adults (>15): N1 = 88, N2 = 229, $.700 > p > .500$;
Children + adolesc. (<21): N1 = 29, N2 = 49, $.700 > p > .500$.

Table 2. The age distribution in the sample from Zwolle.*
*** The dentitions of 27 of the adult individuals (7 identified and 20 unidentified) did not permit age estimations. These individuals had to be omitted from all analyses and tables based on the partition of the sample into age classes.**

3. Problem formulation

Because many of our, only partly published, dental investigations indicated that it is imperative to re-consider our current methods of dental analysis (Bouts et al. 1992a, b; Pot 1986, 1988a, b; Pot & de Groot 1989; Pot et al. 1989), we considered it useful to dedicate the first part of this paper to precisely that subject. We will demonstrate that the comparability of dental research can be highly enhanced by abandoning the habit of expressing the dental health status of a population in terms of overall percentages of caries, even if such results are presented per age class. We will also demonstrate that it is necessary to establish objective standards for the evaluation of carious cavities, periapical lesions, etc. and to be aware of the manner in which the calculated frequencies of pathological phenomena can influence each other.

After this has been done we will present the results of our investigation of the Zwolle material, in which the above methodology has been used and the indicated problems have been taken into account. In our discussion of these results we will illustrate the effects of the applied procedures. Furthermore we will discuss the possible etiology of the observed systematic sex differences in dental pathology.

4. Methods and procedures used in the analyses of the dental data

4A. The functional classes

All our data on dental pathology are presented in terms of the three functional/morphological classes of teeth: 1. the anterior teeth (incisors and canines), 2. the premolars and 3. the molars. This is because the elements in these classes differ in the morphology of their roots and crowns. According to Pot (Bouts et al. 1992a, b; Pot, 1986, 1988a, b, unpublished material; Pot & de Groot 1989; Pot et al. 1989; and vide Nieuwenkamp in prep.) these differences in root morphology, as well as the more slanted position of the molar roots versus those of the anterior teeth lead to a differential post mortem loss of elements (vide below under 4B), with the highest frequencies of loss in the one-rooted elements of the anterior dentition. The same author demonstrated that the prevalence of dental pathology is influenced by the morphology of the crowns. The highest frequencies of lesions are found in the molars, with their complicated occlusal fissure patterns and their broad contact facets. Furthermore their least favourable position in the mouth in relation to the removal of food remains enhances the chances of the occurrence of molar caries.

4B. The preservation rate

The Zwolle sample has first been evaluated in terms of what Pot (1986, 1988a, b) has called the preservation rate (behoudswaarde). By this term we describe the percentage of elements/alveolar sites in the jaw which are available for investigation, in other words, which yield information as to their status or former history. An element or a bone site is considered 'present' when information as to its status or foregoing processes is available, while 'absent' implies non-informative. This leads to the, at first sight paradoxical, situation that an ante mortem lost element is included in the group 'present' (Bouts et al. 1992b, 1993). For the same reason, dental germs which are not yet (fully) erupted (vide Section 4C, point 1) are registered as 'present', even when they are invisible in the jaw, except when they clearly have been lost post mortem. In the calculation of the preservation rate for deciduous dentitions, elements which have already been exfoliated are also registered as being 'present', when their location in the jaw is present and intact. This is because in both latter cases we know with almost complete certainty the processes which are transpiring and/or have transpired.

As indicated in Section 4A, Pot has demonstrated that differential preservation rates usually occur (Pot 1988b, unpublished material; Pot & de Groot 1989; Pot et al. 1989; and vide Section 5 of this paper) between the dental elements of the three functional classes. For the alveolar sites such patterning has not been observed by Pot. Furthermore it is clear that the presence/absence of alveolar sites and the presence/absence of dental elements are mutually related to a considerable extent. The former is almost exclusively dependent upon post-depositional processes. The presence/absence of the elements, on the other hand, except in those cases where they have been found disarticulated from the jaw, depends upon the presence or absence of the bone sites as well as upon other post-depositional processes causing their loss.

The degree of pathology present in the jaw is another factor influencing the preservation rate of the dental elements. However, the relationship with dental pathology is complex. Periapical lesions and alveolar atrophy are expected to cause a decrease of the numbers of preserved teeth, while, as we have seen above, ante mortem lost elements are informative as to their dental status and as such are counted as present. This leads to the paradox that samples with a high degree of dental pathology are expected to show a decreased preservation rate due to the influence of periapical lesions and alveolar atrophy, but an increased preservation rate, due to the influence of ante mortem loss. It will be seen below that these complex relationships influence the calculated frequencies of pathological lesions to a considerable extent.

Plate 1. Root rest, resulting from a carious lesion in the maxilla of a man in the estimated age class 25-50.

Plate 2. Severe attrition (6- to 6) in the maxilla of a man in the estimated age class 45-70

4C. Registration

Our observations have been registered by using a computer programme, specifically designed for this purpose, which is being developed by Bouts and Verhoeven. It has been described already in several publications (Bouts & Pot 1989; Bouts et al. 1992a; Constandse-Westermann 1997).

Because of our awareness that the registration of the dental status by different investigators often lacks conformity, we present here the definitions which have been employed by us in scoring our observations. This is not to pretend that our way of registration would be better than others, but to stress the need to be precise in this respect.

1. An element has been registered as 'erupted' only when complete occlusion had occurred. Elements still in the process of erupting have been registered as 'germ'.

2. Brown or white discolorations of the enamel have not been registered as carious lesions, in view of the difficulty of distinguishing intra vitam lesions from post mortem discolorations. 'Caries present' indicates a clear cavity with undermined edges, which can be entered with a probe.

3. Only when a clear periapical cavity has been observed has a 'periapical lesion' been registered, i.e. this has not been done in the case of infected alveolar bone lacking such a cavity.

4. 'Ante mortem loss' indicates a completely resorbed alveole. Sites with incompletely filled alveoles and absent elements have been inserted in the category 'post mortem loss', because the moment when the element lost its articulation with the jaw cannot be determined. In such cases possibly preceding periapical lesions could not be observed and were therefore not recorded (vide Section 4D, point 1). This procedure leads to minimum values for the percentages of ante mortem loss and periapical lesions.

5. When it was not clear whether a site without an alveole originated from ante mortem loss, congenital absence or retarded eruption, the site was scored as 'element absent, no alveole', without further specification. Also this leads to minimum ante mortem loss percentages.

6. The presence of only root rests may be a consequence of a carious lesion or of severe attrition. The difference between these two situations is usually clearly visible (Plates 1 and 2). In the first case the phenomenon has been registered by the code 'root rest' and the element was included as such in the calculation of the percentage of carious elements. In the second case it was registered by the codes 'element present' and 'attrition 7' and not included in the category 'carious'.

7. Carious cavities have been recorded for those facets of the teeth on which they were observed. When only one tooth facet was affected, this was also the facet on which the caries had originated. In the case of two affected facets, however, the facet of origin of the carious cavity could not be determined. Facets which had been completely destroyed by the caries process were always recorded as carious.

4D. Related and non-related pathological phenomena/processes and their bearing upon our analyses/interpretations.

A number of pathological phenomena/processes is mutually related by their etiology, i.e. the relationship between caries, periapical lesions, ante mortem tooth loss and other associated phenomena. This has a bearing upon the possibilities/strategies used for their interpretation and subsequent analysis. However, we have used such etiological relations only in those cases where the material itself provided insight into their quantitative aspects. Therefore we adhered to the following rules.

1. In addition to caries, also alveolar resorption and pocket formation, as well as any other kind of lesion, may lead to ante mortem tooth loss. However, inspection of the dental remains only provides limited insight into the quantitative aspect of such etiology versus caries and subsequent periapical lesion. Therefore we have not interpreted ante mortem loss in terms of previously present caries or a previously present periapical lesion. This procedure results in a certain bias of all percentages of caries and periapical lesions toward minimum values.

This problem has also been attacked by Lukacs, who presented a sample-specific method for the adjustment of the caries percentages (Lukacs 1995). However, we have not used his solution in this paper. In the first place we have some objections to his method on theoretical grounds. These will be discussed further in our Section 6B2. In the second place we have already published caries percentages for the sample described here in other (Dutch) publications and we wish to avoid the confusion created by different sets of figures being published about the same dental sample.

2. Scoring periapical lesions is impossible when the element cannot be removed from the alveole. However, in those cases where the element could be removed it was observed that healthy-looking alveolar bone, tightly fitting around an element, of which the pulp cavity was not exposed, was hardly ever affected by a periapical lesion. In the Zwolle material this occurred in only two elements/alveolar sites in all the 334 adult dentitions which were studied. Therefore we felt justified to include the locations, where the element could not be removed due to tightly fitting alveolar bone, in our

analyses in the category 'periapical lesion absent'. This procedure was followed in all cases, except when the pulp cavity of the element was exposed (vide below under 3.) or when this diagnosis was otherwise contradicted, e.g. by the indication of such a lesion by a fistula in the surface of the jaw or by the affected alveole of a neighbouring element.

3. On the other hand, locations with a similar outward appearance but with an exposed pulp cavity were included in the category 'periapical lesion present'. This procedure was also followed for loose elements with exposed pulp cavities. This decision was based on the observation that in 311 of the 315 cases (98.7 %), where the inspection of both phenomena was possible, an exposed pulp cavity was accompanied by a periapical lesion. Therefore we judged that this interpretation would provide the best rendition of the real number of periapical lesions in the dental sample.

4. In those cases where the element and its location could be inspected for caries as well as for periapical lesions, we found that caries was present in 138 of the 143 cases of periapical lesions in the female sub-sample but in only 121 of the 161 cases in the male sub-sample (vide Table 13). We will discuss this difference between the sexes in Sections 5 and 6. The relevant figures from Table 13, per functional class of elements and per age class, have been used to adjust the total percentages of caries for those cases where caries could not be scored directly, i.e. 'element absent, periapical lesion present'.[2]

4E. The calculations; observability

Despite the above possibility (Section 4D, point 4) to adjust the percentages of caries in the case of periapical lesions, combined with post mortem lost elements, the possibility of scoring caries is biased by ante mortem and post mortem loss and by the occurrence of broken crowns. Because of this, even the adjusted absolute counts of carious elements, augmented by the number of 'root rests' (vide Section 4C, point 6), lead to minimum estimates, especially in the higher age classes. As a solution, we have calculated caries percentages on the basis of the numbers of only those elements where caries, if present, could have been scored, as the possible total. However, as we will see below, this only partially solves the problem and still leads to minimum estimates of the caries frequencies.

Similar problems pertain to the absolute numbers of periapical lesions, in this case augmented by the numbers in the category 'exposed pulp cavity, periapical location invisible or absent' (vide Section 4D, point 3). For the same reasons as above (post mortem loss of the alveolar location, ante mortem loss of the element), these absolute counts are minimum estimates. Here also percentages have been calculated on the basis of the numbers of observations which would have been possible, as a partial solution to the problem.

A similar procedure has been followed in the calculation of the percentages of ante mortem loss. Here too the absolute counts are minimum numbers, due to the post mortem loss of parts of the jaws. Furthermore, without the use of radiological equipment the possibilities to discern between ante mortem loss, congenital absence and retarded eruption are limited. This is especially the case for the third molars, where both congenital absence and retarded eruption occur most frequently and macroscopic inspection of the configuration in the jaw is less decisive than, e.g. in the case of congenitally absent lateral incisors in an otherwise complete and healthy dentition. It is clear that using the registration procedure described above (Section 4C, point 5), the percentages of ante mortem lost elements are still minimum estimates, despite the adjustment in their calculation.

5. The Zwolle sample

5A. The preservation rate

5A1. The deciduous dentitions

For the deciduous dentitions we do not expect systematic differences between the two functional classes (anterior teeth and molars) to be apparent. This expectation is based upon the fact that the distribution of the preservation rates over these two classes of deciduous elements is extremely dependent upon the numbers of germs versus those of erupted and functioning teeth, i.e. the chance of post mortem loss is considerably higher for the latter category than for germs. Rendition of these relationships would only be possible by partitioning the sub-adult material into one- or, at most, two-year age classes, which is not feasible in the material treated here. Therefore in Table 3 we present the overall percentages for the deciduous dentitions, not partitioned according to the functional classes. The table shows that preservation of the deciduous elements and bone sites is lower than that of the permanent dentitions, below. The difference between the percentage for the elements and that for the bone sites (statistically significant; $\Sigma X^2 = 22.696$, d.f. = 1, $p < .001$) shows that there is a large number of deciduous teeth, which has been found removed from the jaw.

	Percentage informative	N (indiv.)
Dental elements	59.0 %	65
Bone sites	49.7 %	65

Table 3. The preservation rates for the deciduous dentitions in the Zwolle material.

5A2. The permanent dentitions

In Table 4 the preservation rate of the Zwolle material is presented for the permanent dentitions, per estimated age class and per functional class. These data were analyzed to investigate the predicted differences in the frequencies of informative teeth between the three functional classes. Visual inspection of the table shows that the preservation of the bone sites is independent of these classes. This is contrary to the preservation of the elements, which shows its dependence upon root morphology, especially for the anterior teeth versus the premolars and molars. Statistical tests confirm the above visual impression. Using Chi-Square Two-Sample tests (Siegel 1956: 104-111) and Fisher Multiple Contingency tests (Verbeek et al. 1983; Verbeek & Kroonenberg 1990) and setting our level of significance at $p \leq 5\,\%$[3], we observed only two out of a possible 15 statistically significant differences between the three functional classes in the preservation of the bone sites. These two differences are related, being both caused by a relatively bad preservation of the molar sites in the 45-70 year age class. For the elements, on the other hand, we found eight out of 15 significant differences, all indicating decreased preservation rates of the anterior teeth versus those of the premolars and the molars. These two latter functional classes showed no statistically significant mutual differences. The results of similar tests of the various separate sub-samples (males versus females, identified versus unidentified individuals) were consistent with the above general pattern, indicating the strength of that patterning and the homogeneity of our sample in this respect.[4]

The table further shows that, except in the adolescent age class, the preservation of the bone sites is higher (in ten out of twelve cases significantly) than that of the elements. The adolescents (no statistically significant differences) have an intermediate position in this respect between the children (Table 3) and the adults. The above demonstrates the dependence of the preservation of the elements upon that of the bone sites. Such dependence is present in almost all samples studied by Pot (Pot 1986, 1988a, b, unpublished material; Pot & de Groot 1989; Pot et al. 1989) except when, by extremely careful excavation, the majority of the teeth which were present, but removed from the jaw, has been recovered. More detailed analyses of the relationships between the preservation of bone sites and that of elements have shown that these relationships are strongest for the molars and the premolars. As predicted, the anterior teeth are often subject to 'extra' loss, unrelated to the loss of bone sites.

Finally we iteratively compared the preservation rates of the dental elements between the five age classes, per functional class, in order to investigate in more detail the complex relationship between dental pathology, increasing with age, and these preservation rates. However, no clear patterning could be discerned. This is probably due to the counterbalance of two opposite effects. Periapical lesions and alveolar atrophy, on the one hand, would tend to increase post mortem loss and therefore decrease the preservation rate. Ante mortem loss, on the other hand, leads to increased preservation rates as explained in Section 4B.

In the absence of clear age influences we finally calculated overall preservation values for the three functional classes. Between 66.0 % (anterior teeth) and 74.3 % (premolars) of the elements in the adult permanent dentitions rendered information as to their status, while the preservation rate of the bone sites varied between 79.2 % (molars) and 82.0 % (premolars) for the three functional classes. When we compare these figures to the preservation rates of other Dutch dental samples (Perizonius & Pot 1981; Pot 1988b, unpublished material; Pot & de Groot 1989; Pot et al. 1989) we observe that the percentages of teeth and bone sites rendering relevant information are higher in the Zwolle sample than in almost all other samples. This is mainly due to the careful planning and execution of the excavation of the Zwolle material.

	PERCENTAGE INFORMATIVE			N (indiv.)
Dental elements*				
Age class	Anterior teeth	Premolars	Molars	
13-21	72.0 %	75.0 %	71.2 %	11**
22-30	63.0 %	74.0 %	72.3 %	25
25-50	71.1 %	79.9 %	76.0 %	72
45-70	64.4 %	69.7 %	70.4 %	99
>65	66.0 %	75.0 %	76.2 %	111

Chi-Square Two-Sample tests:
Anterior teeth/premolars: 4 out of 5 differences statistically significant
Anterior teeth/molars: 4 out of 5 differences statistically significant
Premolars/molars: no statistically significant differences

Bone sites*				
Age class	Anterior teeth	Premolars	Molars	
13-21	66.7 %	68.2 %	65.9 %	11**
22-30	76.0 %	75.0 %	75.3 %	25
25-50	85.6 %	86.3 %	84.0 %	72
45-70	82.5 %	81.4 %	77.3 %	99
>65	80.9 %	82.7 %	78.0 %	111

Chi-Square Two-Sample tests:
Anterior teeth/premolars: no statistically significant differences
Anterior teeth/molars: 1 out of 5 differences statistically significant
Premolars/molars: 1 out of 5 differences statistically significant

Table 4. The preservation rates for the permanent dentitions in the Zwolle material.

*** In the adult age classes (≥ 22) the difference in preservation between the bone sites and the elements is statistically significant in ten out of twelve cases by Chi-Square Two-Sample tests.**
**** The apparent discrepancy with Table 2 is caused by one individual of ca. 13 years old which, according to our criteria, possesses (only) a permanent dentition**

	Nr. of indiv.***	Nr. of ind. with carious elements	Nr. of carious elements	Percentage carious elements**			
				Anterior teeth	[n]	Molars	[n]
3- 6	11	6	20	1.8 %	[56]	32.2 %	[59]
6- 9	4	3	17	10.0 %	[20]	50.0 %	[30]
9-12	4	2	5	(0.0 %)	[5]	(31.2 %)	[16]
12-15	2	1	2	(66.7 %)	[3]****	(0.0 %)	[2]
Total	21	12	44				

Table 5. Caries in the deciduous dentitions of 21 children between 3 and 15 years, per age class: [n] = the number of elements available for inspection.*

*** The figures in parentheses are based on a relatively small number of elements available for inspection (< 20). Therefore these figures must be viewed as rough indications of the real percentages in this skeletal population, in the respective age class and functional class.**
**** The calculations are based on the fully erupted elements only. In the not, or partly erupted elements no cavities occurred.**
***** This column contains only those individuals in the respective age classes of which (part of) the deciduous dentition was available for inspection.**
****** One of the three anterior deciduous elements, which were available for inspection in this age class, had an exposed pulp cavity.**

Age class	Nr. of indiv.***	Nr. of ind. with carious elements	Nr. of carious elements	Percentage carious elements**					
				Anterior teeth	[n]	Premolars	[n]	Molars	[n]
3- 6	11	0	0	(0.0 %)	[8]	-	[0]	(0.0 %)	[3]
6- 9	4	1	2	(0.0 %)	[5]	-	[0]	(12.5 %)	[16]
9-12	5	2	3	0.0 %	[33]	(0.0 %)	[12]	15.0 %	[20]
12-15	4	2	8	10.0 %	[20]	(0.0 %)	[13]	(40.0 %)	[15]
15-21	10	7	37	8.6 %	[93]	7.8 %	[64]	34.8 %	[69]
Total	34	12	50						

Table 6. Caries in the permanent dentitions of 34 children and adolescents between 6 and 21 years, per age class; [n] = the number of elements available for inspection.*

*** *Vide* Table 5, note 1.**
**** *Vide* Table 5, note 2.**
***** This column contains only those individuals in the respective age classes of which (part of) the permanent dentition was available for inspection.**

5B. Dental pathology

In this section it will be demonstrated that in Zwolle there is a considerable difference in the frequency of dental pathology between the adult males and females. Therefore it was necessary to keep the sexes separate in all analyses of the adult sub-sample. For the children's and adolescents' remains, on the other hand, the analysis of the identified sub-sample did not indicate the existence of sex differences in dental pathology. Therefore the pathology of the age classes under 22 has further been analyzed for the combined sexes.

5B1 The children and adolescents

In Table 5 the prevalence of dental pathology among the fully erupted elements of 21 deciduous dentitions is presented. The remains of the other children in these age classes had no completely developed deciduous elements permitting inspection. None of the not, or only partly erupted elements showed any lesions.

These children from Zwolle already suffered from dental pathology at an early age. In the age class 3-6 years half of the individuals had one or more cavities in their deciduous dentitions. In 25 % of these 20 affected elements the pulp cavity was already exposed. As expected the molars are the most strongly affected elements. This trend is repeated in the higher age classes. The cavities are equally distributed over the occlusal, distal and mesial dental facets. Periapical lesions occurred in one 3-6 year old child (in two neighbouring deciduous molars) and in the deciduous canine of one 12-15 year old child.

Table 6 presents the same figures for the permanent dentitions in the sub-sample up to 21 years of age. It shows that most of the recently erupted permanent elements are still healthy. After functioning during a number of years they begin to show cavities, as is seen in the 15-21 year age class. The percentage of exposed pulp cavities, which occurred mainly in the molars, was somewhat lower than in the deciduous dentitions, i.e. 15 %. Obviously the less vulnerable enamel of the permanent elements resists the undermining action of the factors involved in cariogenesis somewhat longer than that of the deciduous dentitions. In the permanent sub-adult dentitions 66 % of the cavities occurred in the occlusal facets. Five individuals between 9 and 21 years together had 10 periapical lesions in their permanent elements. All figures show that dental pathology is not evenly spread among these children and adolescents, but that some of them are conspicuous by their affected dentitions. Finally, <u>ante mortem</u> loss did not occur in individuals up to 21.

5B2. The adults

5B2a. Caries

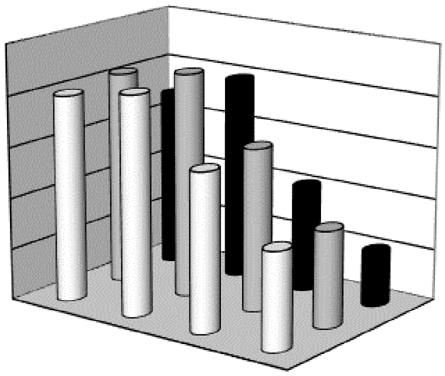
Table 7a shows the percentages of elements permitting inspection for caries for males and females in the four adult age classes, per functional class. Table 7b presents the legend of the accompanying graphic representation, to be used with the Tables 7a through 15. As predicted (Section 4E), few elements are available in the higher age classes, particularly for the molars. In Table 8 the prevalence of caries is presented. It shows the expected increase with age and the predicted (Section 4A) differentiation between the functional classes of dental elements. The fact that the molars are the most vulnerable in this respect is also apparent in an earlier onset of the phenomena in this functional class. This is the case in all samples from The Netherlands investigated by Pot (Perizonius & Pot 1981; Pot 1988b, unpublished material; Pot & de Groot 1989; Pot <u>et al.</u> 1989; and <u>vide</u> Constandse-Westermann 1997 and Nieuwenkamp in prep.). Detailed investigation of these samples indicated that the frequencies of caries are highest in the first molars.

A further phenomenon are the systematic, and in four out of 12 instances statistically significant, differences between the male and the female sub-samples, with the females showing the higher caries frequencies. These differences start to occur in those age classes, where caries is gaining importance and they remain extant in the higher age classes. They are accompanied by other male-female differences. The males show lower frequencies of cases, where the caries has developed into an exposed pulp cavity (0 % - 73 % of the carious elements) than do the females (24 % - 100 %); however, only one of these differences is significant. In the males these percentages increase regularly with age, while in the females no clear age-related pattern is observed (Table 9).

This last observation may be due to the very high percentages of <u>ante mortem</u> loss in the higher age classes of the female sub-sample (<u>vide</u> below), obscuring earlier lesions. In most (male and female) age classes (5 out of 8 cases) the highest frequencies of exposed pulp cavities are in the premolars, giving the impression that, while the molars are the most liable to the onset of caries, the process, after its initial phase, proceeds at a faster rate in the premolars, perhaps due to their lesser mass. Exposed pulp cavities which are <u>not</u> due to carious lesions but to severe attrition, are observed only sporadically in the females (5 out of 144 cases; Table 10). However, they form the majority of the exposed pulp cavities in

MALES

Estimated age class	Number of individuals	Percentages of elements available for inspection		
		Anterior teeth	Premolars	Molars
22-30	3	80.6 %	83.3 %	69.4 %
25-50	23	85.5 %	87.5 %	79.4 %
45-70	41	61.6 %	63.4 %	41.5 %
>65	35	37.9 %	37.5 %	21.2 %



FEMALES

Estimated age class	Number of individuals	Percentages of elements available for inspection		
		Anterior teeth	Premolars	Molars
22-30	14	63.7 %	80.4 %	72.0 %
25-50	28	71.7 %	79.9 %	63.4 %
45-70	28	69.9 %	63.0 %	32.4 %
>65	50	18.3 %	18.5 %	6.3 %

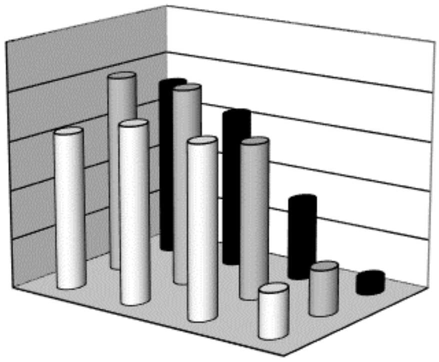


Table 7a. The possibility to record carious lesions in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class.

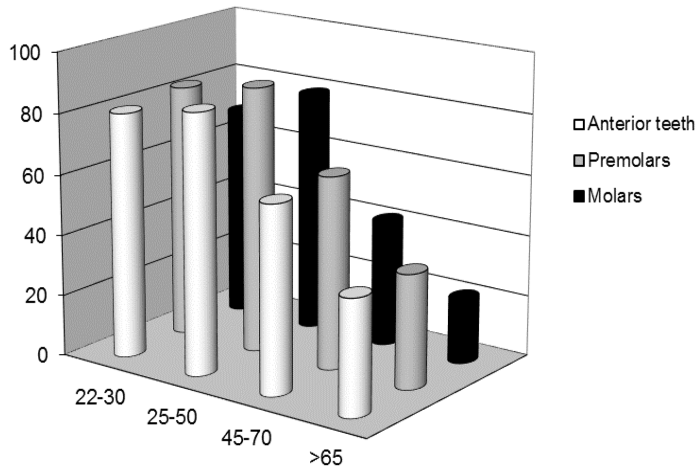
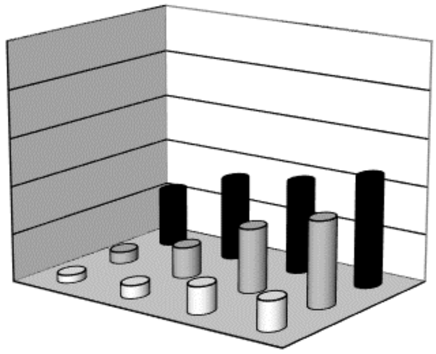


Table 7b. Legend of the graphic representation in Table 7a and in Tables 8-15.

MALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	3.4 %	[29]	5.0 %	[20]	24.0 %	[25]
25-50	5.5 %	[236]	13.0 %	[161]	34.2 %	[219]
45-70	11.6 %	[303]	26.9 %	[208]	38.5 %	[205]
>65	12.6 %	[159]	36.2 %	[105]	46.1 %	[89]



FEMALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	3.7 %	[109]	5.6 %	[90]	16.5 %	[121]
25-50	10.0 %	[241]	10.1 %	[179]	38.0 %	[213]
45-70	26.4 %	[235]	31.2 %	[141]	47.7 %	[109]
>65	52.7 %	[110]	52.7 %	[74]	71.0 %	[38]

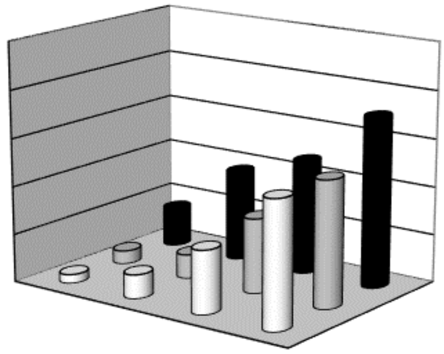


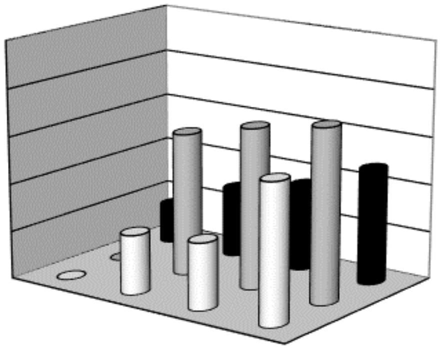
Table 8. The prevalence of caries in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class; [n] = the number of elements available for inspection (*vide* Table 7).

* Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:

Age class	Anterior teeth	Premolars	Molars
22-30	$p = 1.000$	$p = 1.000$	$p = .393$
25-50	$.100 > p > .050$	$.500 > p > .300$	$.500 > p > .300$
45-70	$\underline{.010 > p > .001}$	$.500 > p > .300$	$.200 > p > .100$
>65	$\underline{p < .001}$	$\underline{.020 > p > .010}$	$\underline{.010 > p > .001}$

MALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(0.0 %)	[1]	(0.0 %)	[1]	(16.7 %)	[6]
25-50	(25.0 %)	[8]	60.0 %	[20]	29.4 %	[68]
45-70	28.0 %	[25]	67.4 %	[43]	36.2 %	[47]
>65	(58.3 %)	[12]	72.7 %	[22]	48.3 %	[29]



FEMALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(33.3 %)	[3]	(100.0 %)	[5]	(42.1 %)	[19]
25-50	33.3 %	[21]	(75.O %)	[12]	43.6 %	[55]
45-70	24.4 %	[45]	51.8 %	[27]	61.5 %	[39]
>65	50.0 %	[30]	48.0 %	[25]	(56.2 %)	[16]

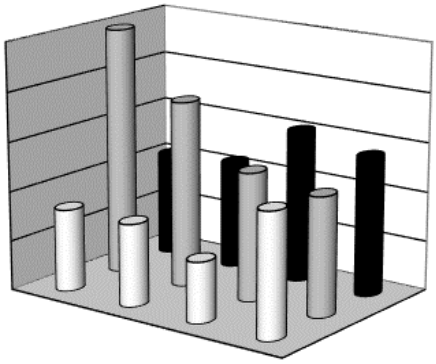


Table 9. Carious elements with exposed pulp cavities, given as percentages of the total numbers [n] of carious elements available for inspection.*

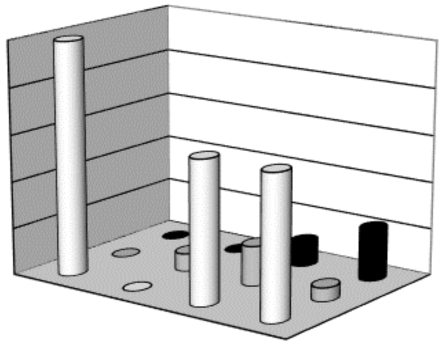
* *Vide* Table 5, note 1. In this table the uncorrected caries frequencies had to be used. This explains the differences between this table and Table 8.

** Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:

Age Class	Anterior teeth	Premolars	Molars
22-30	$p = 1.000$	$p = .167$	$p = .364$
25-50	$p = 1.000$	$p = .465$	$.200 > p > .100$
45-70	$.800 > p > .700$	$.200 > p > .100$	$\underline{.020 > p > .010}$
>65	$.700 > p > .500$	$.100 > p > .050$	$.200 > p > .100$

MALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(100.0 %)	[1]	-	[0]	(0.0 %)	[1]
25-50	(0.0 %)	[2]	(7.7 %)	[13]	0.0 %	[20]
45-70	(61.1 %)	[18]	17.1 %	[35]	(10.5 %)	[19]
>65	(61.1 %)	[18]	(5.9 %)	[17]	(22.2 %)	[18]



FEMALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(0.0 %)	[1]	(0.0 %)	[5]	(0.0 %)	[8]
25-50	(0.0 %)	[7]	(0.0 %)	[9]	4.0 %	[25]
45-70	(0.0 %)	[11]	(0.0 %)	[14]	0.0 %	[24]
>65	(6.2 %)	[16]	(7.7 %)	[13]	(18.2 %)	[11]

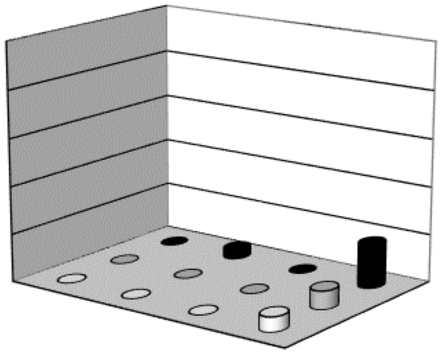


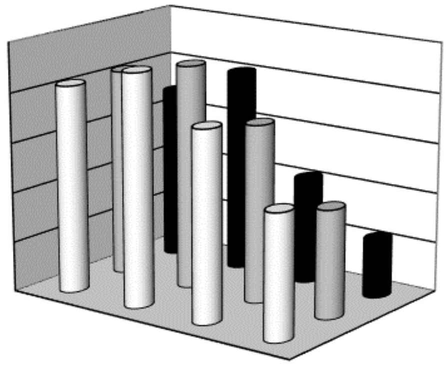
Table 10. Elements with exposed pulp cavities, not related to a carious lesion, given as percentages of the total numbers [n] of elements with exposed pulp cavities.*

* *Vide* Table 5, note 1.
** Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:

Age Class	Anterior teeth	Premolars	Molars
22-30	no valid result	no valid result	no valid result
25-50	no valid result	$p = 1.000$	$p = 1.000$
45-70	$\underline{p = .001}$	$p = .164$	$p = .189$
>65	$\underline{p < .001}$	$p = 1.000$	$p = 1.000$

MALES

Estimated age class	Number of individuals	Percentages of bone sites available for inspection		
		Anterior teeth	Premolars	Molars
22-30	3	83.3 %	83.3 %	69.4 %
25-50	23	92.8 %	89.7 %	81.2 %
45-70	41	76.0 %	71.0 %	42.5 %
>65	35	49.8 %	43.2 %	23.3 %



FEMALES

Estimated age class	Number of individuals	Percentages of bone sites available for inspection		
		Anterior teeth	Premolars	Molars
22-30	14	81.6 %	84.8 %	77.4 %
25-50	28	87.5 %	86.2 %	68.4 %
45-70	28	86.6 %	70.5 %	35.1 %
>65	50	29.5 %	22.0 %	7.5 %

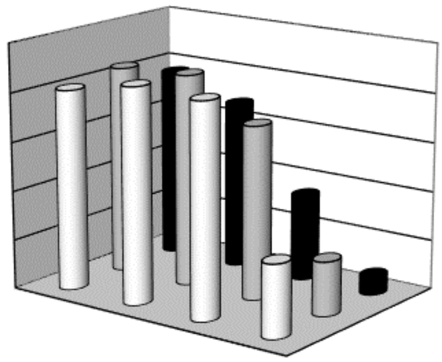
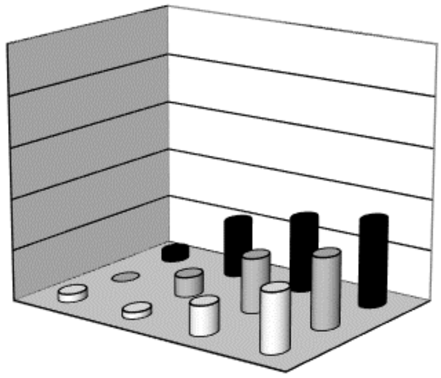


Table 11. The possibility to record periapical lesions in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class.

MALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	3.3 %	[30]	0.0 %	[20]	(4.0 %)	[25]
25-50	2.7 %	[256]	7.9 %	[165]	21.8 %	[124]
45-70	11.8 %	[374]	21.5 %	[233]	28.7 %	[209]
>65	23.4 %	[209]	28.1 %	[121]	33.7 %	[98]



FEMALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	1.5 %	[137]	5.3 %	[95]	6.9 %	[130]
25-50	3.4 %	[294]	7.8 %	[193]	22.2 %	[230]
45-70	10.0 %	[291]	19.6 %	[158]	33.0 %	[118]
>65	26.0 %	[177]	31.8 %	[88]	55.6 %	[45]

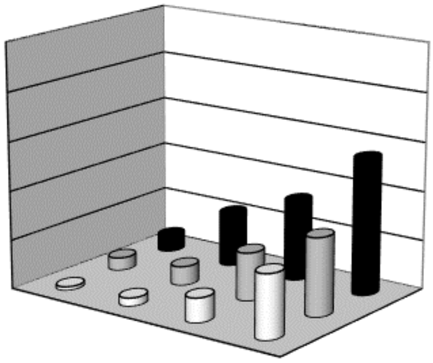


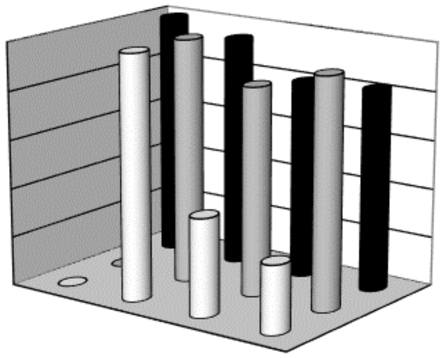
Table 12. The prevalence of periapical lesions in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class; [n] = the number of bone sites available for inspection (*vide* Table 11).

*** Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:**

Age class	Anterior teeth	Premolars	Molars
22-30	p = 1.000	p = .614	p = .703
25-50	.700>p>.500	.980>p>.950	.950>p>.900
45-70	.500>p>.300	.700>p>.500	.800>p>.700
>65	.700>p>.500	.700>p>.500	<u>.020>p>.010</u>

MALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(0.0 %)	[1]	-	[0]	(100.0 %)	[1]
25-50	(100.0 %)	[2]	(100.0 %)	[11]	(94.7 %)	[19]
45-70	40.0 %	[20]	85.3 %	[34]	81.0 %	[21]
>65	(27.8%)	[18]	(94.1%)	[17]	(82.4 %)	[17]



FEMALES**

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	(100.0 %)	[1]	(100.0 %)	[5]	(100.0 %)	[7]
25-50	(100.0 %)	[7]	(100.0 %)	[8]	95.8 %	[24]
45-70	(100.0 %)	[12]	(100.0 %)	[14]	100.0 %	[26]
>65	(93.3 %)	[15]	(92.9 %)	[14]	(80.0 %)	[10]

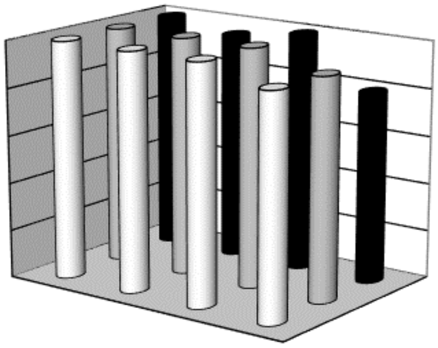


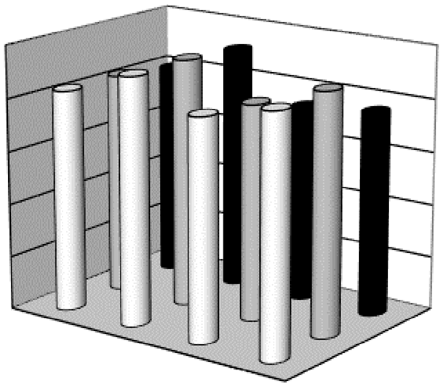
Table 13. The frequencies of periapical lesions directly related to earlier carious processes, given as percentages of the total numbers [n] of periapical lesions available for inspection of this phenomenon.*

* *Vide* Table 5, note 1.
** Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:

Age Class	Anterior teeth	Premolars	Molars
22-30	no valid result	no valid result	no valid result
25-50	no valid result	no valid result	$p = 1.000$
45-70	$\underline{p = .002}$	$p = .303$	$\underline{p = .034}$
>65	$\underline{p < .001}$	$p = 1.000$	$p = 1.000$

MALES

Estimated age class	Number of individuals	Percentages of bone sites available for inspection		
		Anterior teeth	Premolars	Molars
22-30	3	83.3 %	83.3 %	80.6 %
25-50	23	93.1 %	93.5 %	91.7 %
45-70	41	83.1 %	81.4 %	74.2 %
>65	35	89.8 %	90.7 %	76.7 %



FEMALES

Estimated age class	Number of individuals	Percentages of bone sites available for inspection		
		Anterior teeth	Premolars	Molars
22-30	14	83.9 %	86.6 %	85.1 %
25-50	28	93.2 %	93.8 %	89.6 %
45-70	28	96.4 %	94.6 %	81.2 %
>65	50	86.2 %	86.5 %	61.0 %

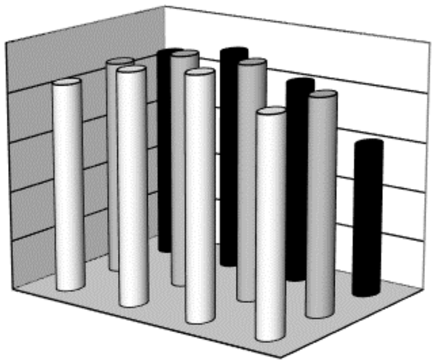
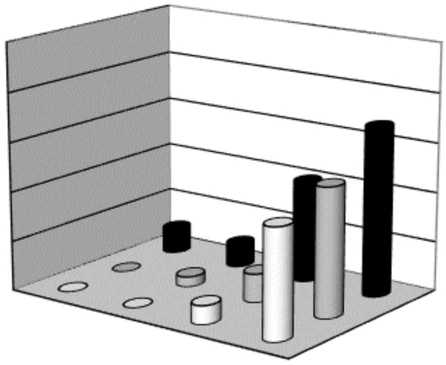


Table 14. The possibility to record *ante mortem* tooth loss in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class.

MALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	0.0 %	[30]	0.0 %	[20]	10.3 %	[29]
25-50	0.0 %	[251]	4.1 %	[172]	9.5 %	[253]
45-70	7.6 %	[409]	11.6 %	[267]	41.1 %	[365]
>65	44.3 %	[377]	52.0 %	[254]	68.3 %	[322]



FEMALES*

Estimated age class	Anterior teeth	[n]	Premolars	[n]	Molars	[n]
22-30	1.4 %	[141]	0.0 %	[97]	4.2 %	[143]
25-50	3.2 %	[313]	6.7 %	[210]	20.3 %	[301]
45-70	9.3 %	[324]	25.0 %	[212]	52.8 %	[273]
>65	63.6 %	[517]	74.6 %	[346]	86.6 %	[366]

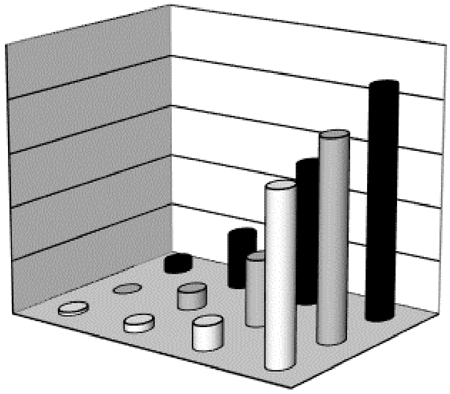


Table 15. The prevalence of *ante mortem* tooth loss in the dentitions of 222 adults (102 males and 120 females), per estimated age class and per functional class; [n] = the number of bone sites available for inspection (*vide* Table 14).

*** Differences between males and females by Fisher Exact Probability or Chi-Square Two-Sample tests, as appropriate:**

Age Class	Anterior teeth	Premolars	Molars
22-30	$p = 1.000$	no valid result	$p = .360$
25-50	$\underline{p = .006}$	$.300 > p > .200$	$\underline{p < .001}$
45-70	$.500 > p > .300$	$\underline{p < .001}$	$\underline{.010 > p > .001}$
>65	$\underline{p < .001}$	$\underline{p < .001}$	$\underline{p < .001}$

the anterior teeth of the males in the two highest age classes (22 out of 36 cases in total; Table 10). All the above differences will be discussed below (in Section 6C).

Finally the distribution of the cavities over the five dental facets has been studied. In the anterior teeth distal and mesial cavities form the majority (in males 50.0 % and 34.2 % respectively, in females 47.8 % and 39.1 %), while lingual caries hardly occurs. In the premolars the picture is largely similar (46.7 % distal and 41.7 % mesial caries in males, 41.8 % and 49.1 % in females), accompanied by some buccal and, in this functional group also some occlusal cavities. In the molars we find 36.6 % (males) and 47.6 % (females) occlusal caries, accompanied by high percentages of buccal and mesial, somewhat less distal and hardly any lingual cavities. Further details are to be found in Bouts et al. (1992b). The females show, on the average, more affected tooth facets per carious element than do the males.

5B2b Periapical lesions.

For the periapical lesions, a number of similar phenomena can be observed. Also here, the number of elements/bone sites for which the phenomenon can be registered decreases with age. In the individuals above 65 years of age hardly a sufficient number of bone locations (or elements with exposed pulp cavities) can be used to calculate reliable percentages (Table 11). Table 12 presents the increase, with age, of the percentages of periapical lesions and the increase of same from the anterior teeth to the molars.

Contrary to our observations pertinent to caries, the percentages of periapical lesions do not show any substantial systematic differences between the sexes (only in the >65 age class is the difference for the molars statistically significant). This may partly be due to the procedure, followed in our interpretation of the registered data (vide under Section 4D, point 2) which may slightly over-estimate the number of healthy sockets, thus reducing the percentages of periapical lesions to minimum estimates. X-ray inspection may lead to slightly higher percentages and possibly to male/female differences. The biases mentioned in Sections 4C, point 4 and 4D, point 1, both leading to diminished observability, may also be causative to the lack of sex differences in this respect. This (absence of) sex difference is further discussed in Section 6C.

As discussed already above (Section 4D, point 4) we also analyzed the relationship between the occurrence of caries and that of periapical lesions (Table 13). This analysis pertains to all those elements/bone locations for which both phenomena, if present, could have been registered. Contrary to the above, we do observe differences between the male and the female sub-samples in this respect, three of which are statistically significant. Almost all periapical lesions could be related to an earlier carious process, except 30.0 % of such lesions in the males of the two highest age classes, especially 65.8 % in the anterior teeth. This difference is discussed further in Section 6C. As indicated in Section 4D (point 4), the percentages in Table 13 have been used to correct the caries percentages for those cases, where an alveole with a periapical lesion was present, without the possibility to inspect the corresponding element.

5B2c Ante mortem loss

Table 14 shows that ante mortem tooth loss can be registered equally well in all age classes. In fact ante mortem tooth loss forms one of the main causes of the lack of observability of the other two pathological phenomena in the higher age classes. The third molars show the highest percentage 'unobservable' because it is especially for these elements that the cause of the absence of an alveole on its location cannot always be assessed by visual inspection (vide Section 4E).

Table 15 shows the increase with age, and from the anterior teeth to the molars, of ante mortem loss. In the age class 25-50 this is already the case for 10 % to 20 % of the molars. The anterior teeth and the premolars are lost at a later age and less frequently than the molars. As for the caries percentages, there is a consistent difference between the males and the females, which is observed in all age classes (seven out of 12 statistically significant differences).

5B3 Dental health in Zwolle.

The frequencies of the three pathological phenomena necessarily pertain to different total numbers. Furthermore, these frequencies as well as the observability of the different lesions are mutually dependent. Because of the above, we also calculated the percentages of completely healthy elements in the deciduous and permanent dentitions of our sample, this being the best overall measure for dental health.

Combining these percentages with those of pathology showed the following. The deciduous dentitions of the children over 3 years of age contained on the average 3 or 4 (3.8) carious elements. Most of these occurred in the older children's dentitions. Their remaining deciduous teeth were healthy (93 % of the anterior teeth and 64 % of the molars). In the permanent dentitions of all children and adolescents the prevalence of cavities was less, i.e. they occurred in just under

2 elements per individual. Between 96 % (premolars) and 81 % (molars) of the permanent elements of the children in the age classes between 3 and 15 years and the adolescents (15-21 years) were completely healthy.

In the lowest adult age class over 90 % of the available anterior teeth is healthy and 68 % (males) to 78 % (females) of the molars and their bone sites. The dentitions of the males of this age class contained already three to four (3.5) elements with cavities, one of which was usually accompanied by a periapical lesion. These males had also lost, on the average, one of their dental elements, i.e. they possessed an average of 27 or 28 healthy teeth. The average female from the same age class had nearly three (2.7) carious teeth, one or two (1.5) of which with a periapical lesion. Some of them already missed one element, leading to an average of somewhat over 28 (28.2) healthy teeth per (young) woman.

The situation in the highest age class was dramatically different. Here the percentages of healthy elements are 32 % (males) and 11 % (females) for the anterior teeth and 14 % (males) and 2 % (females) for the molars. The males in this class missed 17 or 18 (17.5) of their teeth. Of the remaining elements four had cavities and four (partly the same) had periapical lesions, leading to an average of only seven or eight (7.7) healthy elements per male. For the females dental health was even worse. By that age they had lost 23 or 24 (23.5) of their teeth, with five cases of caries and three periapical lesions in the remaining dentition. Per woman, only two or three (2.3) healthy elements remained. More details can be found in Bouts et al. (1992a, b, 1993).

Except for those possible, but unassessible cases, where ante mortem tooth loss was the result of extraction of an element by a dentist or a barber, there are no signs of restorative dentistry in our sample. The above description of the dentitions makes it clear that their condition must have had a considerable detrimental influence on the general health status of the members of this social group.

6. Discussion

The predicted differences between the preservation rates of the dental elements in the three functional classes are clearly present in the Zwolle material. The mutual relationships between the frequencies (percentages) of the various pathological phenomena in the Zwolle sample are also in agreement with our predictions. They are lowest in the anterior teeth and highest in the molars, and their increase with age is evident.

6A. The preservation rates

The differential preservation rates, in combination with the differential occurrence of pathology in the three functional classes, clearly indicate the impracticability of all global percentages of pathological phenomena, even when these have been calculated separately for males and females and for the various age classes. Such percentages are often mutually incomparable e.g. between samples with a good preservation of the anterior teeth, on the one hand, and samples where the majority of the dental material consists of molars, on the other. Calculation of the percentages per functional group and, for large samples, even per element (Pot, 1988b, unpublished material) is an absolute necessity for obtaining results which are comparable between dental samples.

Our attempt to find patterning in the preservation rates for the various age classes, in order to elucidate the relationship between dental pathology, being age-related, and the preservation of the dentitions, was not successful. In our Zwolle sample we could demonstrate neither a decrease nor an increase in the preservation rate with age. However, in Constandse-Westermann & Bouts (in press) the influence of ante mortem loss on this rate is demonstrated by the comparison of the data on Zwolle to those on another dental sample.

6B. Dental pathology

6B1. Epidemiological aspects

The analysis has made it clear that the relationships between the various forms of dental pathology are complex and must be monitored closely in any dental study. We have not only seen that post-depositional processes (post mortem loss of elements and/or alveolar bone, broken crowns) influence the possibilities for the registration of pathological phenomena, but also that these phenomena themselves influence each other's observability. This is particularly the case for ante mortem loss. As ante mortem loss is age-dependent, as well as etiologically related to caries and periapical lesions, the possibilities for registering the latter two phenomena are both age-dependent and biased. In other words, ante mortem loss precludes the observation of caries and periapical lesions, especially for those elements which are likely to have been affected by either of these two forms of dental pathology in an earlier stage of the development of the dentition.

Percentages of caries and/or periapical lesions pertaining to the higher age classes are therefore less reliable, being based on the relatively small and biased numbers of elements which can be inspected. In all age classes, but increasingly with age, the percentages of both phenomena will be minimum estimates. As to the periapical processes, our registration method described above (under 4D, point 2), although providing the best possible rendition of the prevalence of the phenomenon, also tends to minimalize the resulting frequencies.

The possibilities for registering ante mortem loss do not differ systematically between the age classes. However, we have seen above that here too our percentages will be minimum estimates. Therefore, despite our careful adjustments in the interpretation of the results and our attempt to calculate the percentages in the most reliable and realistic manner, we are convinced that in all investigations of archaeological dental material we can only hope to obtain minimum estimates of the frequencies of dental pathology which, as such, are incomparable to the results of modern epidemiological investigations of dental pathology.

6B2. Lukacs' 'Caries Correction Factor', some observations.

In our analysis of the data we have proposed some solutions for the problems described in Section 6B1. Lukacs has also drawn attention to these problems and has proposed a different solution (Lukacs 1995). In fact, his procedure is based upon the same principles as ours. However, we derive our correction factor from our analysis of the etiology of the periapical lesions, while Lukacs proposes to use the etiology of ante mortem tooth loss for this purpose.

In note 5 the result of the application of Lukacs' method to our data is presented.[5] We observe some rather striking differences with our own figures, especially in the higher age classes. The figures also indicate, that some of these caries percentages are based to a considerable extent on extrapolation. Comparison of the n-values with those in our Table 8 shows that the application of Lukacs' method in fact more than doubles the 'totals' for the highest age class. It remains to be seen whether in samples with such high percentages of ante mortem loss, causing this discrepancy, Lukacs' method still leads to valid results.

A further reason to consider these results with some caution is, that Lukacs' method is based on the premise, that ante mortem loss is caused either by severe attrition or by carious lesions. As that author himself already indicates, this may not be the case for all dental samples. For instance, especially in samples with high proportions of dental and parodontal pathology, alveolar atrophy may be an important third cause of ante mortem loss. Therefore, in our case Lukacs' method may well lead to inflated caries percentages.

A last remark pertains to Lukacs' method as such. By its application, a number of dental elements is introduced twice into the estimate of the degree of dental pathology of the population in question, i.e. once as being lost ante mortem, and once as having (had) caries. This explains the high 'totals' mentioned above. In his publication Lukacs does not indicate how he handles this overestimation of the total dental pathology in the dental sample. Furthermore, the extra cases of caries resulting from the application of his method, were not actually present at the moment of death of the individuals in question. Instead, they were present in some earlier stage of their life-time, not related to their ages at death in any specific manner. These earlier cases of caries are then added by Lukacs to the frequencies of carious lesions actually present in the dentitions at the moment of death of the same and other individuals. However, many lesions in that last category may have developed only a short time before their death and may not have been present contemporaneously with the earlier cases resulting from Lukacs' extrapolation into the past. This is another reason to expect that Lukacs' method may lead to an inflated estimate of the actual degree of dental pathology in the population at any specific moment in time. At any rate, the frequencies calculated in this fashion cannot be related to the age at death profile of the population in question. In view of the strong dependency of the caries frequencies upon the age classes this is a severe drawback of Lukacs' method. Instead of trying to obtain "an accurate estimate of the true caries rate" (Lukacs 1995: 155) for a skeletal series, it may be better to realize that the results of prevalence studies of skeletal populations are extremely unlikely to represent those of any normal cross-sectional study of the living (Waldron 1994, 1996). Therefore, accurate reporting of our computational procedures can at best lead to mutual comparability of the results of different skeletal studies. Paleopathological 'prevalence' figures will never be comparable to those derived from modern epidemiological studies.

6B3. Caries per dental facet

Contrary to the above, the distribution of the carious lesions over the various facets of the teeth (Bouts et al. 1992b) is largely in accordance with the results of a modern dental epidemiological investigation of 845 recent dental statuses of Dutch professional soldiers (1958-1977; Meeuwissen & Eschen 1984), with one notable exception. In their results, these authors observe significantly (Chi-Square Two-Sample test, $\Sigma X^2 = 86.447$, d.f. = 4, $p < .001$) higher percentages of occlusal and, thereby, lower percentages of mesial and distal cavities in the premolars than was the case in our 19th century Zwolle sample. We suspect that the lack of restorative dentistry in Zwolle, has led to this difference. A cavity which originally initiates on the small occlusal facet of a premolar will rapidly expand in a mesial or distal direction when no restorative treatment is applied. In the molars, with their much larger occlusal facets this has probably happened to a lesser extent.

PIPE-SMOKING

	Certain	Most probably	Total	[N]
Males	43	6	49	102
Females	0	1	1	120
Sex indet.	15	1	16	112

Table 16. Pipe-smoking in Zwolle in the late 18th/early 19th century AD.

6C. Male/female differences

A final point to be discussed here are the systematic differences in the frequencies of carious lesions and ante mortem loss and the lack of such differences in the frequencies of periapical lesions between our male and female sub-samples. A partial explanation of the differences pertaining to caries is the differential rapidity of the attrition process (the attrition rate) between the sexes. This difference pertains especially to the anterior teeth. The males show a higher anterior attrition rate. Most probably this is a result of their habit of smoking earthenware pipes, with a round stem (Plates 3 and 4; Table 16). Maat & van der Velde (1987) have shown that severe attrition can scour away a superficial cavity. Furthermore the constant movement and scouring of the stem of the pipe precludes plaque formation. This would lead to less, or less serious cavities in the male dentitions, particularly in the anterior teeth, than in those of the females. Both the occurrence of exposed pulp cavities, not related to carious lesions, and of periapical lesions, unrelated to earlier cavities, in the anterior teeth of the older men (Tables 9, 10 and 13), can be readily related to their pipe smoking. Clarke & Hirsch (1991) indicate that extreme attrition is always accompanied by continuous eruption of the element in question, diminishing the hold of the element onto its socket. Exposition of the pulp cavity is in most cases followed by necrosis and abscesses, affecting the surrounding alveolar bone after having reached the apex. The latter phenomenon explains also the absence of sex differences in the frequencies of periapical lesions, in contrast to the observed differences in the caries and ante mortem loss frequencies. The males in our sample have a number of 'extra' periapical lesions, not caused by previous caries. This obscures the higher frequencies of 'other' dental pathology in the female sample.

However, the differences between males and females occur not only in the anterior teeth but also in the molars and premolars, especially ante mortem loss. Therefore there must be other factors which have caused those differences. Unfortunately we have no relevant information about possible differences in food patterns between men and women in the late 18th and early 19th centuries in The Netherlands. As far as is known, excessive alcohol consumption, having a detrimental influence on dental and gingival health (Visser 1989), occurred in both males and females. The claimed (Etter 1989) positive influence of tobacco chewing on oral health is, in fact, poorly documented, as is the influence of tobacco chewing and smoking on dental and parodontal health in general (Koopman 1979; Visser 1980).

The results of epidemiological investigations of recent Dutch samples do not yield consistent results on the subject of sex differences in dental pathology. Publications note no (Pot & Groeneveld 1978; Pot et al. 1980; Schaub et al. 1978), small (de Baat & Snijder 1982; van den Berg 1984) or significant (Houwink et al. 1985; Kalsbeek et al. 1989) differences in the frequencies of caries and gingival infections between the male and the female individuals in the various children, adolescent and adult samples. The results of investigations of other than Dutch material show similar inconsistency (Bennike 1985; Burns 1979; Dünninger & Pieper 1991; Frayer 1989; Heloe & Haugarden 1981; Hillson 1986; Larsen 1983; Larsen et al. 1991; Legler & Menaker 1980; Lukacs 1996).

The physiological influence of pregnancy and lactation on the health of the dentitions and their surroundings consists principally of the frequent occurrence, in many (not all) populations, of gingivitis in pregnant women (Arafat 1974; Löe 1965; Trip 1988), which may in some cases lead to earlier tooth loss. Additionally the effect of frequent vomiting, creating a temporary acid environment in the mouth (vide Visser 1983) has been mentioned in this respect. Behavioural factors may also play a role (eating habits during pregnancy, negligence of dental hygiene, etc.) (Pot pers. comm., Kwant pers. comm.). However, an investigation of the dental health of women who had been pregnant in comparison to nulliparae did not indicate a difference between these two groups (Kwant pers. comm.).

Apart from pregnancy-related influences, other behavioural factors have been suggested to cause differences in dental pathology between males and females. These concern differential access to food sources, as well as differences in the pattern and frequency of eating between women (the cooks in virtually all societies) and men (König 1970; Larsen 1983; Larsen et al. 1995). However, in view of the absence of data on nutritional patterning or other relevant information on behaviour, the inconsistency of the comparable information, the poor quality of the documentation of all possible explanatory factors, and the multi-causal origin of the different forms of dental pathology (Larsen et al. 1995; van Palenstein Heideman & Huis in 't Veld 1982) we must refrain here from giving a satisfactory explanation of the sex difference in dental pathology in the Zwolle sample.

Plate 3. Typical attrition pattern resulting from frequent pipe-smoking in the dentition of a 47-year-old man.

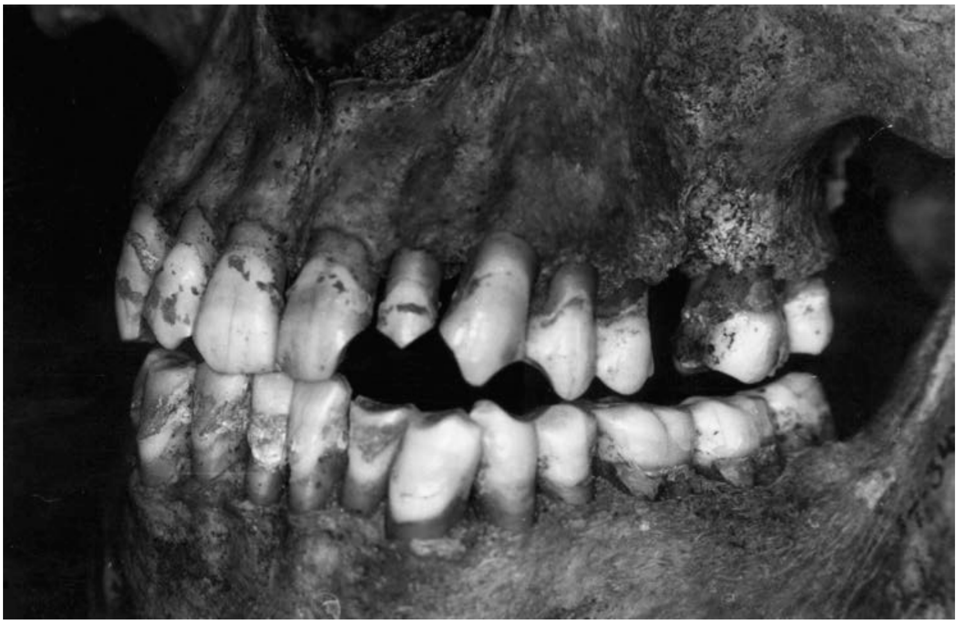
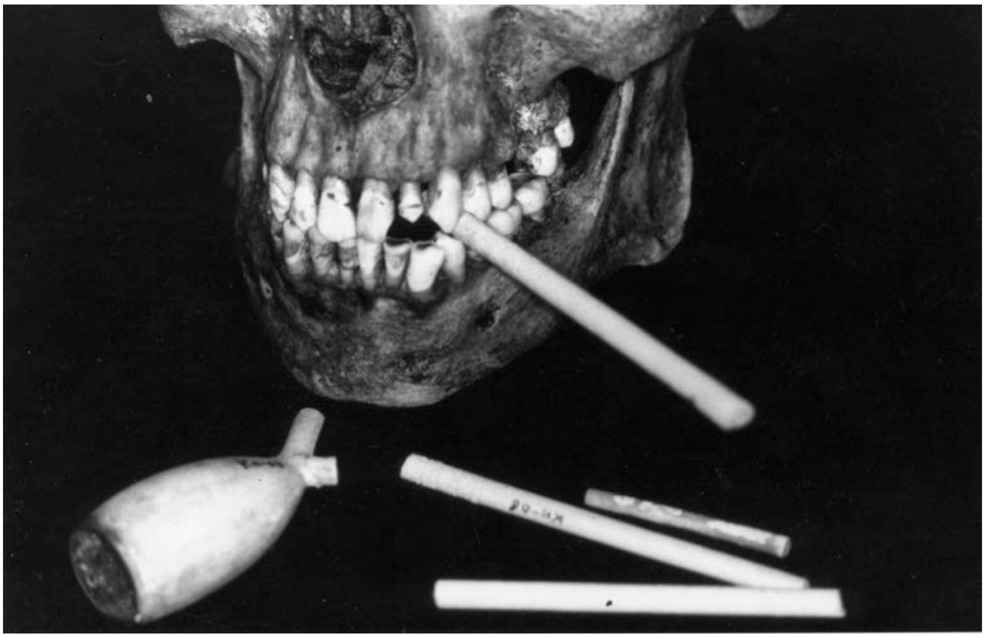


Plate 4. The same dentition as in Plate 3. The stem of the earthenware pipe of those days fits perfectly in the hole.



7. Conclusions

Most aspects of the conclusions to be drawn from the results of our analysis have already been presented in the foregoing section. The biased nature of all archaeological dental samples and their incomparability to modern epidemiological samples have been discussed. Furthermore the necessity has been demonstrated to give a detailed account of all computational and analytical procedures used. All of these dimensions of the analysis of data on excavated human skeletal and dental remains have recently been stressed by Waldron (1994, 1996) within the more general framework of paleopathology. It is our firm conviction that all skeletal and dental samples, giving only a partial rendition of the 'real world', contain inherent, sometimes severe, biases. Part of these biases usually is a consequence of the general nature of the samples (archaeological cemetery samples), another part may well be more sample-specific. All such biases should be closely monitored during the analysis. We fully agree with Lukacs (1995) and Waldron (1994, 1996) that methods must be designed to meet the specific needs of 'epidemiological' investigations of archaeological samples of human remains.

8. Endnotes

1. The combination of the calendar ages of the individuals in the identified sub-sample and the estimated ages for the unidentified, larger, sub-sample did not create problems for the sub-adult age classes. In our other publications (Bouts et al. 1992; Constandse-Westermann 1997) it was demonstrated, that a satisfactory agreement exists between the real and the estimated ages of the children and adolescents in the identified group. Furthermore the age distributions did not differ significantly between the two sub-samples. This permitted us to combine the real ages of the identified and the estimated ages for the unidentified individuals in the presentation of the sub-adult age distribution.

For the adult group, on the other hand, such a procedure appeared problematic, because differences between the real and the estimated ages remained extant in 20 % of the cases (Bouts et al. 1992). The best solution to this problem was to use the estimated ages of all individuals, according to our calibrated interpretation (Constandse-Westermann 1997).

2. This has been done using the formula:

$$(A/B).C$$

to calculate the number with which the frequency of carious elements is to be augmented. In this formula:
A = the number of bone locations with a periapical lesion, with the dental element present and with caries;
B = the total number of bone locations with a periapical lesion, with the dental element present; and
C = the number of bone locations with a periapical lesion, with the dental element absent, usually due to post mortem loss.
This formula has been applied for the male and the female sub-samples separately, per age class and per functional class.

3. All tests were evaluated for their two-tailed probability values. In all instances, the large numbers of individuals within our samples rendered the chance of Type I errors, i.e. rejecting H_0 when in fact it is true, smaller than that of Type II errors, i.e. accepting H_0 when in fact it is false. Therefore $p \leq .050$ could be used as the highest probability level for rejecting H_0, thereby reducing the number of Type II errors to an acceptable level (Siegel 1956). The tests which have been used are:
the Chi-Square Two-Sample test (Siegel 1956: 104-111);
the Kolmogorov-Smirnov Two Sample test (Siegel 1956: 127-136);
the Fisher Exact Probability test (Siegel 1956: 96-104); and
the Fisher Multiple Contingency test (Kroonenberg et al. 1983; Verbeek & Kroonenberg 1990).

4. All test results which could not be included in this paper can be obtained from the authors upon request.

5. The caries percentages calculated according to Lukacs (1995) are as follows:

Age class	Anterior teeth	Premolars	Molars
Males			
	% [n]	% [n]	% [n]
22-30	3.45 [29]	5.00 [20]	32.14 [28]
25-50	5.51 [236]	16.07 [168]	40.74 [243]
45-70	14.07 [334]	34.31 [239]	60.00 [355]
> 65	26.07 [326]	68.35 [237]	68.61 [309]

Females

22-30	5.41 [111]	5.56 [90]	20.47 [127]
25-50	13.55 [251]	16.58 [193]	51.09 [274]
45-70	34.72 [265]	50.00 [194]	77.47 [253]
> 65	83.37 [439]	83.43 [332]	80.65 [355]

The above figures result from the application of Lukacs' correction method to the figures of our Table 8.

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