DIACHRONIC ODONTOLOGICAL CHANGE: 17 ADULT SKELETAL POPULATIONS FROM THE NETHERLANDS

T.S. Constandse-Westermann, F.C. Nieuwenkamp and Tj. Pot

Introduction

During the period 1977 to approximately 1992 Pot executed intensive studies on the dentitions of 17 Dutch skeletal populations, dating from the end of the 3rd century AD up to 1858.[1] His main aims were: 1. improvement of the method for age estimation from dental attrition and 2. the investigation of diachronic changes in the occurrence of dental pathology in The Netherlands. Unfortunately his work was published only partially (Bouts *et al.* 1992a. 1992b, 1993; Bouts & Pot 1989; Perizonius & Pot 1981; Pot 1986, 1988a, 1988b; Pot & de Groot 1989; Pot *et al.* 1989), almost all publications were in the Dutch language, and of a number of samples the original data sheets were not even analyzed. During the years 1998-2003 the material was (re)studied by Nieuwenkamp, within the framework of a master's thesis (Nieuwenkamp 2003). Full data on 14 and partial data on three adult dental samples are now available. The most important results of the analyses by Pot and by Nieuwenkamp are published in this article, treating diachronic change in adult dental pathology in The Netherlands.[2]

Material and methods

The information on the skeletal samples which are discussed in this study is in some cases minimal. Others have been more amply documented. The skeletal populations in question are listed below, in chronological order. Their geographical position is indicated in Figure 1 and their main characteristics are summarized in Table 1.

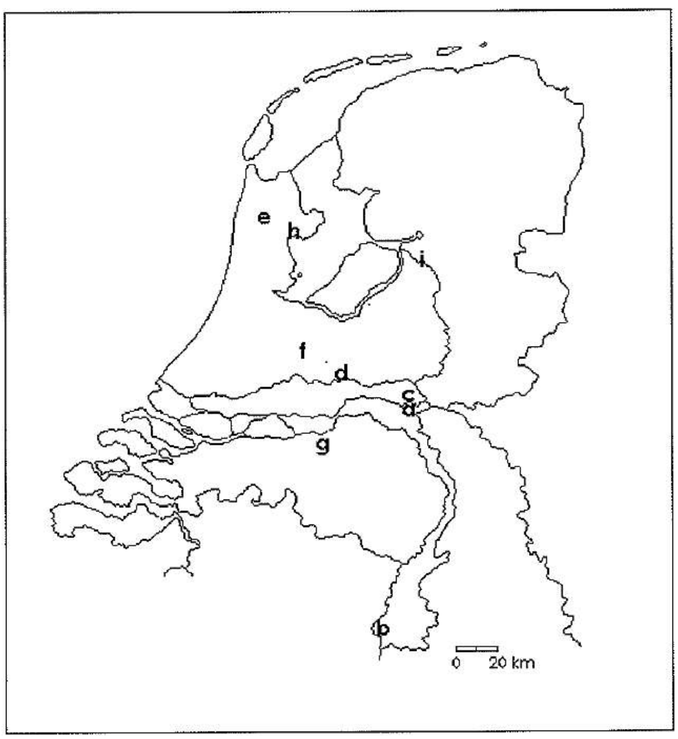

Figure 1:

Map of The Netherlands with the locations of the excavation sites.

a. Nijmegen (NIJ/MAJ)
b. Maastricht (MAA/BO)
c. Lent (LENT)
d. Wijk bij Duurstede (DOR/ENGK; DOR/HEUL; WBD/FRA)
e. Blokhuizen (BLKKH)
f. Utrecht (UT/STJAC; UT/JOH; UT/J0B/pi; UT/JOB/gr)
g. 's-Hertogenbosch (B0/Ml/mo; BO/ENG; BO/MI/lay; BO/STJAN)
h. Hoorn (HOORN)
i. Zwolle (ZWO/BROE)

DENTAL SAMPLE	DATE	NR. OF SUB-ADULT INDIV. (<21)	NR. OF ADULT INDIV.	NR. OF INDIV. ORIGINALLY PRESENT IN CEMETERY*	AVAILABLE DATA** I	II	III	IV
NIJ/MA	end 3^{rd} - end 4^{th} cent. AD	13	111	*ca.* 850		*	*	
MAA/BO	7^{th} - begin 8^{th} cent. AD	13	20	at least 54		*	*	
LENT	630 - *ca.* 750 AD	28	47	*ca.* 130	*			*
DOR/ENGK	*ca.* 700 - *ca.* 850 AD	46	212	??	*	*	*	
DOR/HEUL	*ca.* 700 - *ca.* 850 AD	3	88	at least *ca.* 2350	*	*	*	
BLOKH	*ca.* 1000 - 1170 AD	38	77	??	*	*	*	
WBD/FRA	*ca.* 850 - *ca.* 1700 AD	58	408	??		*	*	
UT/STJAC	*ca.* 1175 - *ca.* 1450 AD	45	46	??	*		*	
BO/MI/mo	*ca.* 1200 - *ca.* 1400 AD	0	26	45		*	*	
UT/JOH	*ca.* 1200 - 1528 AD	6	95	103***	*		*	
HOORN	*ca.* 1400 - *ca.* 1500 AD	2	68	??	*	*	*	
BO/ENG	end 13^{th} - 19^{th} cent. AD	7	36	at least a few hundred		*	*	
BO/MI/lay	*ca.* 1575 - 1629 AD	11	123	??		*	*	
UT/JOB/pi	*ca.* 1500 - *ca.* 1650 AD	61	287	??	*	*	*	
UT/JOB/gr	*ca.* 1650 - *ca.* 1800 AD	35	149	at least 2500	*	*	*	
ZWO/BROE	*ca.* 1775 - 1829 AD	34	307	at least *ca.* 1700	*	*	*	
BO/STJAN	*ca.* 1775 - 1858 AD	50	179	at least 421	*	*	*	

* For most samples this is an estimate, provided by the archaeologist. For the samples MAA/BO, BO/ENG and BO/STJAN it is the number of graves/individuals which has been recovered on the excavated part of the cemetery. For ZWO/BROE the (conservative) estimate was made by one of us (TSCW) on the basis of the number of graves present in the church and the average content per grave.

** I = Preservation value according to Pot; II = Observability of caries, periapical lesions and *ante mortem* tooth loss; III = Dental pathology per attrition group and per functional group; IV = Dental pathology, but in less detail.

*** Almost all men.

Table 1: The 17 samples. Dates, numbers of individuals and available data.

LINK to details of samples listed in Table 1.

As stated, the main goal of this study is the investigation of diachronic variability between the adult dentitions of these 17 skeletal populations and possibly the establishment of diachronic trends in the frequencies of dental pathology (*i.e.* caries, periapical lesions and *ante mortem* tooth loss). Data on the sub-adult dentitions are also available, but due to their small numbers and their mixture of deciduous and permanent elements these were less suitable for diachronic analysis.

We are aware of and have taken into account the intricacy and complexity of scoring the three above categories of dental pathology, resulting from the causal connection between them in the majority of cases (Bouts *et al*. 1992b: and *vide* e.g, Lukacs [1995] and contained sources). We have chosen to avoid this discussion in this short paper. Instead, the three categories of pathology have been analyzed separately. The methodology of their scoring has been identical in the 17 samples.[4] It must further be mentioned here that all scoring has been executed by one and the same investigator, Tj.P. This guarantees optimal mutual comparability of the results.

In view of 1. the results of other investigations on secular trends in dental pathology, *e.g*. Caselitz (1998), 2. surveys of the development of caries in relation to acculturation, *e. g*. Cran (1959), Mayall (1970) and Pedersen (1939), and 3. the extant information on dietary changes in Europe since the beginning of our era, an increase of dental pathology over time is to be expected. However, in order to execute a reliable diachronic analysis it must first be investigated whether the samples are equivalent and mutually comparable regarding non-diachronic factors, which may influence the possibilities to reliably score dental lesions and/or the actual or apparent differences in the incidence of dental pathology between the samples. The degree of control over such sample-dependent variability must be raised to the highest possible level. Only after having accomplished this and after having obtained insight into the possible influence of other factors which cannot or only partly be controlled, can the results be evaluated in diachronic terms.

a. Controllable non-diachronic variation

Earlier investigations (Pot 1988b: Pot & de Groot 1989: Pot et al. 1989) strongly suggest that the possibility to investigate the incidence of dental pathology in each specific dental sample is to a considerable degree dependent upon some specific inherent qualities of the sample itself. Before drawing conclusions on the presence or absence of diachronic trends in the material, these qualities have been examined in the samples which are the subject of this study.

In the first place the possibilities to score dental pathology depend upon what Pot defined as the 'preservation value', *i.e.* how many dental elements, *c.q.* alveolar locations in the jaws, are actually present in the sample. Such numbers/percentages may differ considerably between samples, due to depositional and post-depositional processes, including the quality of their excavation. Obviously, all percentages of dental pathology should be calculated in relation to the preserved numbers.

However, this preservation value actually varies between the three categories of dental pathology, *e.g.* in some cases it is possible to score a periapical lesion at a specific alveolar location in the jaw, while the scoring of (earlier) caries is impossible, due to the post mortem loss of the element. Another example is that of *ante mortem* tooth loss, where it is not the presence but, on the contrary, the absence of the element which yields the information.[4] Therefore Pot's preservation value should in fact be calculated for each of the three categories of pathology separately. This procedure has been followed in this study. Instead of Pot 's specific term 'preservation value' the more general term 'observability', respectively for caries, periapical processes and ante mortem tooth loss, is used here.

During the investigation of the Zwolle material (Bouts *et al.* 1992a, 1992b, 1993) it was noticed that in this sample the observability of caries and periapical lesions decreased gradually with age. while that of ante mortem loss showed no. or at best a very slight decline with age. Furthermore it was noticed already by Pot (*op. cit.*: *vide* also Bouts *et al.* [*op. cit.*]) in some of the underlying samples that the possibilities to investigate dental pathology differ systematically between what he called the three <u>functional groups</u> of dental elements: front teeth (incisors and canines), premolars and molars. Pot attributed this to the differential *post mortem* loss of the dental elements, due to the morphological differences between them (in general, more front elements with their single, usually straight roots, are lost than are premolars and molars). As far as the available data allowed it, the observability of caries, periapical lesions and ante mortem tooth loss has been systematically investigated in all samples.

Not only the observability, but also the frequencies of dental pathology themselves are expected to show systematic variation, in the first place, obviously, with age. As a consequence of the continuously advancing pathological processes, and influenced by the advance of dental attrition, the percentages of observable caries and periapical lesions will increase with age. Only in the very high age classes these percentages may decrease, due to the effect of *ante mortem* loss. This latter category of lesions will hardly be present in the earlier age groups and increase steadily with age. For some of the samples the above has already been demonstrated by Pot in the publications mentioned above. In addition to these age differences, in the sample from Zwolle sex differences were also observed (Bouts *et al. op. cit.*).

Furthermore, Pot strongly suggested that the three functional groups of teeth will also differ in their liability to be affected by the different kinds of dental pathology (1988b: *vide* also Sheiham 1997, Hillson 2003). Generally the molars will show the highest liabilities, due to their morphology (strong occlusal fissuring and broad contact facets) and their position in the mouth. favouring food retention.

In view of all the above, the mutual comparability of the 17 samples has been investigated in detail. First the samples have been compared as to their age distributions, using dental attrition as a rough age indicator (*vide* below). Thereafter the observability of caries, periapical lesions and *ante mortem* tooth loss has been analyzed in each of them, separately for the front teeth, the premolars and the molars and for the various age/attrition groups. The tests used were two-sample Chi-Square tests (Newell 1995; Siegel 1964) and Multiple Contingency analysis (Verbeek *et a l.* 1983; Verbeek & Kroonenberg 1990). A two-tailed probability value of $p \leq .05$ has been considered to indicate a significant difference. Comparison of the samples learned, that the incidence of dental pathology through time could only be investigated reliably per age/attrition group, per functional group and per category of dental lesions.

b. Hardly controllable or uncontrollable non-diachronic variation

In addition to the above it must be stated that there is necessarily a large number of other factors influencing, or related to, the degree of dental pathology in the samples, over which but little control can be obtained. In the first place detailed skeletal investigations (*i.e.* on sex, age and pathology) have been executed only on the samples ZWD/BROE and BO/STJAN (Aten 1990, 1992b: Maat *et al.* 2002). This limits the possibilities to consider the results within a wider biological framework.

Secondly, but little knowledge is available on the differences in socio-economic and/or general health status of the populations in question. Three of the samples contain the inhabitants of cloisters, which may have influenced their wealth, their food patterns and therefore their health, two of the samples are from a rather poor hospital population, *etc. etc*. It remains to be seen to what extent all this will have an impact on the results of the diachronic analysis.

A last source of uncontrollable variation is the duration of the period to which some of the samples are dated. Especially the dates on the samples WBD/FRA, UT/JOH and BO/ENG stretch over long periods and show a great amount of overlap with some other samples. This limits their value as indicators of diachronic change.

In view of this last source of variation only limited use of statistical analysis has been made for the diachronic analysis. Only on the 12 samples showing no or only slight mutual chronological overlap a Spearman Rank Correlation analysis was performed (Newell 1995; Siegel 1964), to test the relation between the chronological sequence of these samples and their level of dental pathology. In view of our above expectation as to the directionality of the diachronic changes we have applied one-tailed tests, again considering $p \leq .05$ to be a significant result. Thereafter plots were made of the levels of dental pathology in all samples. Visual inspection of these plots complemented the test results.

Results

a. Sex and age

As stated above, the majority of the samples have not been studied beyond Pot's dental investigations. Only for two of the samples insight into the appurtenance of the dental remains as to sex is available (MAA/BO and ZWO/BROE). In the investigation of the sample BO/STJAN (Maat *et al.* 2002) the dental results have not been linked to the sex attributions or the age classes. Of one other sample (UT/JOH) it is known that it (almost) exclusively consisted of males. The samples BO/MI/mo and HOORN may have consisted largely of males, respectively females, but this has not been confirmed by independent skeletal research. Therefore the analysis of differences in dental pathology between males and females was impossible.

For the age distributions the situation was, in fact, similar. For the sample ZWO/BROE the observations on dental pathology could be linked to age estimations based on further dental and skeletal research (and for part of the sample even to calendar ages from the church registers). For all other samples there were only the dental attrition data to be used. Therefore four attrition groups (Table 2) were defined, to which the individuals of all samples were attributed. All this was accomplished following Pot 's methodology (1986, 1988a, 1988b).[5] For each population these attrition groups represent four successive stages in the individual ageing processes of its members. *i.e.* per population they can be considered to be age groups.

Attrition group I	: Attrition of M2's 2. 2+ and 3-
Attrition group II	: Attrition of M2's 3. 3+ and 4
Attrition group III	: Attrition of M2's 4+. 5 and 5+
Attrition group IV	: Attrition of M2's 6-. 6 and 7

Table 2: The four attrition groups as used in the present study.

Obviously, any absolute (calendar) age estimations based on dental attrition are dependent upon the pace and the linearity of the attrition process in the populations in question. During the investigation of the ZWO/BROE material (Bouts et a l. 1992a, 1992b, 1993) it became already clear that dental attrition was a very slow process in that population. Constandse-Westermann

(1997: Table 1) presented figures, showing that differences in the pace of attrition were extant between many of the populations which are treated in the underlying paper. However, analyzing these figures it was observed that, especially for the first two attrition groups, unimodal distributions were extant over 13 of the 17 dental populations treated in this study. These distributions were only slightly skewed, had a positive kurtosis, and they were approximating the normal distr ibution to a considerable degree. Therefore it was concluded that the necessity of using these attrition groups to roughly represent the age classes would not seriously compromise the results of our diachronic investigation.

DENTAL SAMPLE	SAMPLE N	PERC. OF INDIV. IN ATTRITION GROUP:				DIAGNOSIS:	
		I	II	III	IV	OVER-REPRES. ATTR. GR.	UNDER-REPRES. ATTR. GR.
NIJ/MA	111	85.6%	11.7%	2.7%	0.0%	I	IV
MAA/BO	20	50.0%	20.0%	25.0%	5.0%		
LENT	47	19.2%	25.5%	27.7%	27.7%	IV	
DOR/ENGK	212	33.0%	39.6%	25.0%	2.4%		IV
DOR/HEUL	88	42.0%	44.3%	13.6%	0.0%		IV
BLOKH	77	32.5%	39.0%	26.0%	2.6%		IV
WBD/FRA	408	34.8%	38.2%	25.2%	1.7%		IV
UT/STJAC	46	34.8%	41.3%	17.4%	6.5%		
BO/MI/mo	26	3.8%	42.3%	53.8%	0.0%	III	IV
UT/JOH	95	26.3%	36.8%	35.8%	1.0%		IV
HOORN	68	33.8%	41.2%	14.7%	10.3%		
BO/ENG	36	69.4%	19.4%	11.1%	0.0%	I	IV
BO/MI/lay	123	18.7%	40.6%	35.0%	5.7%		
UT/JOB/pi	287	35.2%	18.8%	15.7%	30.3%	IV	
UT/JOB/gr	149	34.9%	22.8%	12.8%	29.5%	IV	
ZWO/BROE	307	8.1%	23.4%	32.2%	36.2%	IV	I
BO/STJAN	179	55.3%	20.7%	12.8%	11.2%	I	

Table 3: The distributions of the 17 samples over the four attrition groups, and their differential over-, respectively under-representation.

The distributions of the adult individuals over the four age/attrition groups are presented in Table 3 and depicted in Figure 2. The figure shows the considerable heterogeneity of the samples in this respect, which is confirmed by statistical analysis ($p < .0001$). The residuals of the Multiple Contingency analysis showed in which samples the strongest over- or under-representation occurred. These are indicated in Table 3. Detailed testing was executed of the distributions of the available data over the four attrition groups per category of lesions and per functional group. In all these tests the significant heterogeneity between the samples was confirmed. Figure 2 and Table 3 further demonstrate that the representation of attrition group II, showing no over- or under-representation. is the most homogeneous between the 17 samples.

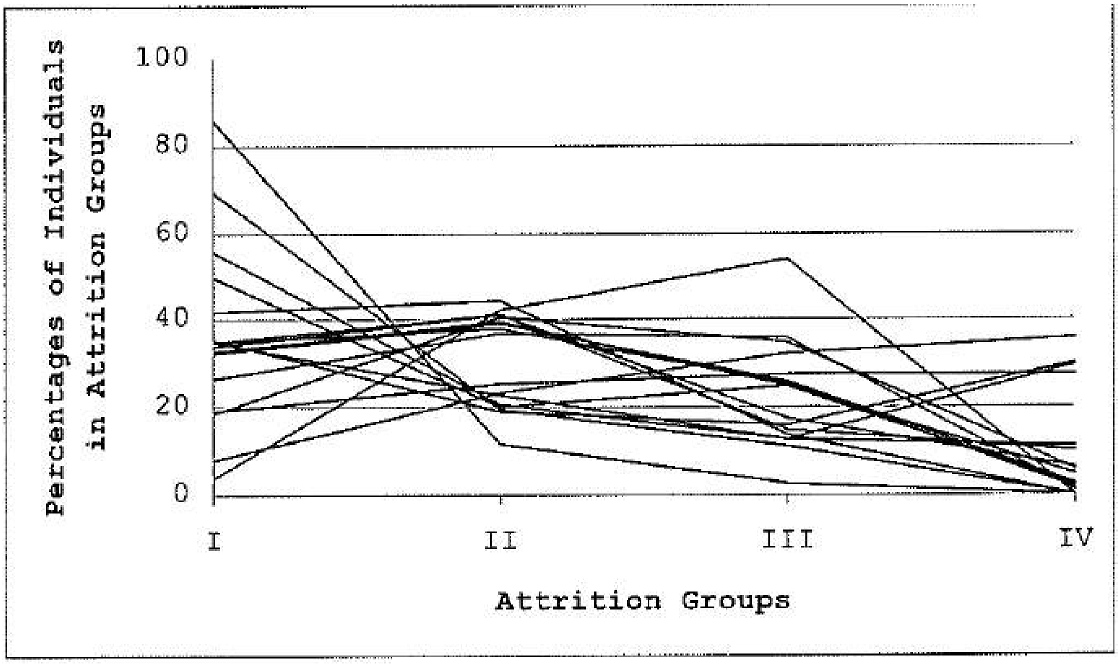

Figure 2: Graphical illustration of the distributions of the 17 samples over the four attrition groups.

Attrition group I contains the largest total number of individuals (719), followed by attrition group II (628). Expressed as percentages per population attrition group II shows somewhat higher values than attrition group I. Attrition groups III and IV contain lower absolute numbers and lower percentages of individuals per population.

b. Observability

Observability percentages could be calculated for each of the three dental lesions for 14 of the 17 samples. In Table 4 the large differences between the samples can be observed for the data on the four attrition groups and the three functional groups, combined into weighted averages. The results per attrition group and per functional group are consistent with the overall picture in Table 4.[6]

The lowest observability values are those on the sample UT/JOB/pi, consistent with the fact that it represents the reburied contents of graves which have been cleared. Other samples with relatively low observability are NIJ/MA (reportedly badly preserved skeletal material) and the three samples from Dorestad/Wijk-bij-Duurstede. The latter three were excavated during extensive campaigns, of which the badly preserved skeletons only formed a small part. The samples from HOORN and ZWO/BROE were excavated with great precision, which shows in their high observability values. The circumstances during the excavation of the sample BO/STJAN were less favourable. Still, the percentages of preserved teeth in these two almost contemporaneous samples are more or less equal, but the numbers of alveolar locations do differ between the two (*vide* Table 4, columns 1 and 3). No information is available as to the possible cause of the difference between the samples BO/Ml/mo and BO/Ml/lay.

DENTAL SAMPLE	OBSERVABILITY ALL ELEMENTS COMBINED: CARIES	PERIAPICAL LESIONS	*ANTE MORTEM* TOOTH LOSS
NIJ/MA	27.5%	35.0%	37.6%
MAA/BO	40.9%	48.0%	52.2%
DOR/ENGK	32.8%	47.0%	50.1%
DOR/HEUL	37.8%	44.6%	46.3%
BLOKH	47.5%	51.7%	57.4%
WBD/FRA	36.0%	44.7%	47.3%
BO/MI/mo	53.1%	62.5%	70.2%
HOORN	47.7%	65.5%	73.2%
BO/ENG	42.5%	50.1%	55.9%
BO/MI/lay	43.0%	53.9%	61.1%
UT/JOB/pi	13.5%	29.2%	37.5%
UT/JOB/gr	31.6%	47.7%	63.2%
ZWO/BROE	41.0%	52.0%	79.6%
BO/STJAN	41.1%	52.3%	61.2%

Table 4: The differential observability of caries, periapical lesions and ante mortem tooth loss between 14 of the samples, for all attrition groups and all functional groups combined.

Notwithstanding the above differences, all systematic variability which was expected could be clearly observed throughout the sarrples. Table 4 shows that in all samples the observability of caries is lower than that of the other two categories of lesions. Periapical lesions take an intermediate position, while *ante mortem* tooth loss is the best observable of the three. This regularity is repeated in the figures per functional group and per attrition group ($p < .001$).[6] Furthermore the observability of caries and periapical lesions is related to the age/attrition groups. Attrition group I generally shows the higher values, closely followed by attrition group II. Attrition groups III and especially IV yield much less information on these two kinds of lesions ($p < .001$). However groups I, II and III hardly differ in relation to the observability of *ante mortem* tooth loss, here it is only attrition group IV which stays behind ($p < .001$).[6] Detailed study of the figures per functional group showed that the observability in attrition group II is the most homogeneous between the 14 populations.

The differential observability of dental pathology in the three functional groups largely confirms Pot's earlier results. Moreover it becomes clear that this patterning of the observability in attrition groups l and II differs from that in attrition groups III and IV. This was investigated for all three categories of dental lesions combined. as well as for each of them separately. In the first two attrition groups the premolars show the highest observability percentages for the three kinds of dental lesions combined, while the observability in the molars is the lowest. The latter (low observability in the molars) is also the case in the attrition groups III plus IV, but here the front teeth generally show higher observability percentages than the premolars. All the above, as well as the detailed results per category of dental lesions, has/have been tested statistically.[7]

Combining the above observations it could be concluded that in the samples studied here the premolars in attrition groups I and II yield the most complete data set, on the basis of which the frequencies of all three categories of lesions can be compared between the samples. Groups III and IV contain less individuals, percentually as well as in absolute numbers, and their observability is lower. The differential observability in the three functional groups yields a complex pattern, largely due to the differential *post mortem* loss of front elements as compared to molars and premolars on the one hand, and bone destruction on the other. It is also possible that the higher liability of molars for all dental pathology (*vide* below) leads to more destruction and loss of those teeth. In this complex pattern the premolars are the most stable elements.

The differential observability of dental lesions between the four attrition groups and the three functional groups dictates that the samples must be tested as to their homogeneity and mutual comparability in these respects. In section a. (Table 2) the significant differences between the age distributions in the 17 samples were already shown. The distributions of the dental samples over the three functional groups were equally heterogeneous. All Multiple Contingency table tests resulted in $\underline{p < .001}$. The residuals show that the strongest heterogeneity was in the samples NIJ/MA, WBD/FRA and ZWO/BROE, followed by DOR/ENGK, UT/JOB/pi, UT/JOB/gr and BO/STJAN. These results clearly indicate that the only reliable manner to analyze the diachronic trends in dental pathology in these samples was to execute this analysis per category of lesions, per functional group and per age/attrition group.

c. Dental pathology

Earlier statistical analyses of the data (Nieuwenkamp 2003, two-sample Chi-Square tests [Newell 1995; Siegel 1964] and Multiple Contingency analysis [Verbeek & Kroonenberg 1990]) confirmed the differential occurrence of caries, periapical lesions and *ante mortem* tooth loss, as already observed by Pot. All dental pathology increases with ag, and the front teeth show the lowest frequencies of pathology, followed by the premolars. The molars show the highest incidence.

In Tables 5, 6 and 7 the frequencies of dental pathology in respectively the front elements, the premolars and the molars in attrition groups I and II are presented for 16 of the 17 samples.[1,8] As far as possible, the samples are ordered chronologically.

A result of the above differences between the four age/attrition groups and between the three functional groups is, that attrition group I hardly allows a meaningful chronological analysis.

ATTR. GROUP / SAMPLE	CARIES I	PERIAP. LESION I	A.M. LOSS I	CARIES II	PERIAP. LESION II	A.M. LOSS II
NIJ/MA	2.7% n=150	0.0% n=230	0.0% n=251	0.0% n=10	0.0% n=24	0.0% n=26
MAA/BO	2.6% n=39	1.8% n=55	0.0% n=57	0.0% n=23	0.0% n=27	0.0% n=27
DOR/ENGK	0.0% n=234	0.2% n=432	0.0% n=442	1.2% n=250	1.1% n=476	1.8% n=491
DOR/HEUL	0.0% n=156	0.0% n=194	0.0% n=198	1.5% n=131	0.0% n=198	0.0% n=202
BLOKH	2.0% n=149	2.0% n=149	0.0% n=188	1.4% n=147	1.1% n=183	4.5% n=199
WBD/FRA	1.1% n=537	0.4% n=779	0.1% n=719	1.1% n=568	0.8% n=849	0.7% n=887
UT/STJAC	0.0% n=?	1.0% n=?	0.0% n=?	6.4% n=?	6.3% n=?	0.0% n=?
BO/MI/mo	0.0% n=10	0.0% n=10	0.0% n=12	0.0% n=58	0.0% n=77	0.0% n=81
UT/JOH	0.0% n=?	0.0% n=?	0.0% n=?	1.9% n=?	1.2% n=?	0.8% n=?
HOORN	0.0% n=120	0.0% n=218	1.3% n=225	1.9% n=158	1.2% n=255	3.4% n=263
BO/ENG	10.7% n=112	3.3% n=153	0.6% n=161	0.0% n=43	0.0% n=49	0.0% n=50
BO/MI/lay	3.5% n=115	0.7% n=150	0.7% n=152	0.7% n=269	2.4% n=377	0.5% n=385
UT/JOB/pi	10.5% n=210	1.6% n=577	1.4% n=590	8.0% n=87	2.8% n=283	2.7% n=295
UT/JOB/gr	10.4% n=326	3.3% n=452	1.9% n=466	17.8% n=191	8.4% n=296	4.6% n=306
ZWO/BROE	4.4% n=182	1.3% n=227	1.7% n=233	7.4% n=597	3.0% n=732	1.5% n=753
BO/STJAN	7.1% n=567	1.7% n=757	1.5% n=779	6.6% n=227	4.9% n=305	4.3% n=322

Table 5: The percentages of caries, periapical lesions and *ante mortem* tooth loss in the front teeth of individuals belonging to attrition groups I and II, in 16 of the 17 dental samples.

	CARIES	PERIAP. LESION	A.M. LOSS		CARIES	PERIAP. LESION	A.M. LOSS
ATTR. GROUP SAMPLE	I	I	I		II	II	II
NIJ/MA	6.5% n=248	1.7% n=300	1.6% n=316		0.0% n=33	0.0% n=50	3.7% n=54
MAA/BO	2.9% n=35	5.3% n=38	0.0% n=39		0.0% n=16	0.0% n=18	0.0% n=18
DOR/ENGK	1.5% n=266	0.3% n=320	0.0% n=315		3.6% n=253	1.8% n=332	4.0% n=350
DOR/HEUL	1.5% n=132	0.0% n=149	0.7% n=152		5.3% n=131	0.7% n=136	0.0% n=140
BLOKH	0.0% n=121	0.0% n=132	0.0% n=137		5.9% n=135	2.2% n=139	1.4% n=147
WBD/FRA	3.7% n=483	1.5% n=542	0.4% n=561		4.3% n=512	2.9% n=584	1.6% n=611
UT/STJAC	4.8% n=?	3.3% n=?	3.0% n=?		15.2% n=?	9.7% n=?	5.1% n=?
BO/MI/mo	0.0% n=7	0.0% n=8	0.0% n=8		4.0% n=50	0.0% n=54	0.0% n=54
UT/JOH	3.1% n=?	2.5% n=?	0.8% n=?		2.9% n=?	3.6% n=?	5.1% n=?
HOORN	0.9% n=225	1.4% n=144	0.7% n=149		1.8% n=166	0.6% n=167	4.0% n=174
BO/ENG	8.2% n=85	5.9% n=101	3.7% n=107		7.7% n=26	7.1% n=28	0.0% n=30
BO/MI/lay	2.2% n=93	1.0% n=100	0.0% n=101		7.3% n=206	4.5% n=246	2.7% n=255
UT/JOB/pi	13.6% n=235	8.5% n=366	6.4% n=393		26.6% n=109	14.7% n=177	8.0% n=201
UT/JOB/gr	15.4% n=246	9.0% n=299	4.4% n=321		25.6% n=121	17.2% n=180	18.6% n=204
ZWO/BROE	6.1% n=147	5.2% n=154	0.6% n=157		9.4% n=424	7.6% n=471	6.0% n=504
BO/STJAN	12.1% n=438	6.3% n=496	2.9% n=514		10.6% n=142	9.0% n=178	15.7% n=216

Table 6: The percentages of caries, periapical lesions and *ante mortem* tooth loss in the premolars of individuals belonging to attrition groups I and II in 16 of the 17 dental samples.

	CARIES	PERIAP. LESION	A.M. LOSS		CARIES	PERIAP. LESION	A.M. LOSS
ATTR. GROUP SAMPLE	I	I	I		II	II	II
NIJ/MA	16.2% n=457	3.8% n=529	1.6% n=571		3.5% n=58	1.3% n=77	2.5% n=80
MAA/BO	26.4% n=53	7.3% n=55	5.0% n=60		27.8% n=18	4.5% n=22	0.0% n=25
DOR/ENGK	4.9% n=371	1.9% n=428	0.9% n=438		9.6% n=374	2.5% n=438	5.1% n=472
DOR/HEUL	6.3% n=191	2.0% n=200	0.5% n=212		9.8% n=174	2.7% n=185	3.0% n=197
BLOKH	8.0% n=187	4.7% n=193	0.0% n=202		14.4% n=174	3.7% n=188	4.7% n=211
WBD/FRA	16.9% n=669	6.5% n=741	2.5% n=799		20.1% n=700	10.1% n=795	6.7% n=891
UT/STJAC	15.8 n=?	11.3 n=?	1.1% n=?		36.1% n=?	21.6% n=?	12.5% n=?
BO/MI/mo	0.0% n=12	0.0% n=12	0.0% n=12		8.7% n=69	4.2% n=71	6.3% n=80
UT/JOH	8.8% n=?	5.2% n=?	4.0% n=?		18.5% n=?	8.4% n=?	12.4% n=?
HOORN	11.1% n=171	7.1% n=198	7.3% n=218		17.2% n=169	9.1% n=209	11.8% n=238
BO/ENG	26.6% n=139	14.3% n=140	4.6% n=173		18.2% n=33	11.1% n=36	21.3% n=47
BO/MI/lay	17.9% n=123	3.9% n=128	3.4% n=145		17.5% n=268	6.9% n=318	8.1% n=382
UT/JOB/pi	32.0% n=306	11.7% n=412	19.1% n=534		27.2% n=125	19.6% n=179	27.0% n=263
UT/JOB/gr	37.6% n=303	15.9% n=358	13.2% n=417		46.9% n=96	31.1% n=151	39.7% n=287
ZWO/BROE	17.9% n=190	7.8% n=204	6.1% n=230		28.1% n=502	15.3% n=583	16.4% n=725
BO/STJAN	24.9% n=555	11.2% n=614	12.5% n=727		23.6% n=144	18.8% n=181	30.2% n=275

Table 7 : The percentages of caries, periapical lesions and *ante mortem* tooth loss in the molars of individuals belonging to attrition groups I and II in 16 of the 17 dental samples.

Especially in the front teeth of attrition group I the still short duration of the impact of the pathological processes and the resistance of the incisors and premolars have resulted in very little differentiation between the samples. The percentages for caries range from zero to 10.7%, and those for periapical lesions and ante mortem loss from zero to 3.3% and from zero to 1.9%, respectively. 19 out of the 48 cells of that table contain zero values. For the premolars the differentiation between the samples is slightly stronger, but in fact, only the molars of attrition group I show clear patterning. In attrition group II, on the other hand, the pathological processes have had a longer duration and, therefore, a much clearer effect.

However, differences between the dating spans of the various samples. chronological overlap and contemporaneity compromise the possibilities to observe chronological trends by visual inspection of the tables. Therefore Spearman Rank Correlation analyses (Newell l995; Siegel l964)of all samples with durations equal to or lower than 200 years were executed, thereby excluding all samples chronologically overlapping with more than one other sample (WBD/FRA, UT/STJAC, UT/JOH and BO/ENG). Complete overlap between two samples could be accounted for by using tied observations. On the 12 samples which were included, 36 tests were performed, for all three pathological processes and for all combinations of attrition groups and functional groups separately. Attrition group IV yielded very defective data, missing data in four to six of the samples and, as shown above, very low observability. The 27 analyses of the data on attrition groups I, II, and III yielded a satisfactory number of 20 significant correlations between chronology and the incidence of dental pathology. Five of the non-significant correlations were in attrition group I, most probably due to the lack of differentiation between the samples in this age class. All of the nine results for attrition group II were significant while in attrition group III this was the case for seven of the nine analyses (Table 8).

		CARIES	PERIAPICAL LESIONS	*ANTE MORTEM* TOOTH LOSS
FRONT TEETH				
Attrition groups:	I	$.05>p>.01$	$p > .05$	$p < .01$
	II	$p < .01$	$p < .01$	$.05>p>.01$
	III	$p < .01$	$p < .01$	$p < .01$
PREMOLARS				
Attrition groups	I	$p > .05$	$p > .05$	$p > .05$
	II	$p < .01$	$p < .01$	$.05>p>.01$
	III	$.05>p>.01$	$p < .01$	$p > .05$
MOLARS				
Attrition groups	I	$p > .05$	$.05>p>.01$	$.05>p>.01$
	II	$.05>p>.01$	$p < .01$	$p < .01$
	III	$p > .05$	$.05>p>.01$	$p < .01$

Table 8: Significance of the Rank Correlation Coefficients between the chronological sequence of 12 of the samples on the one hand, and their percentages of dental pathology on the other.

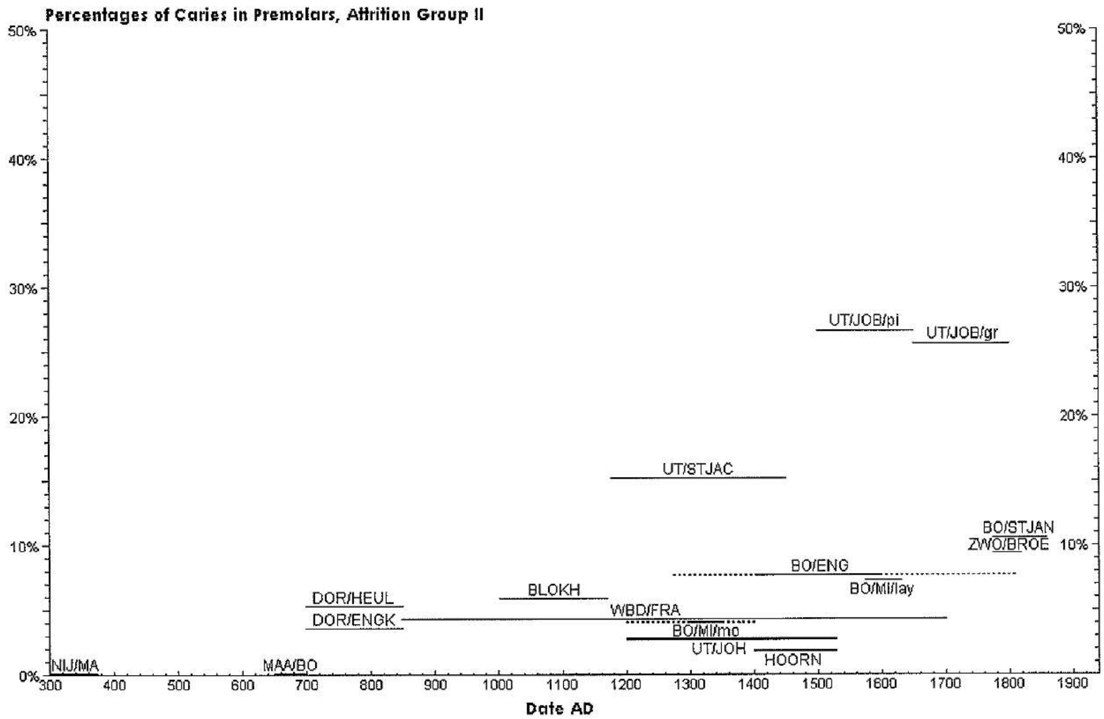

Figure 3: The percentages of caries in attrition group II premolars.

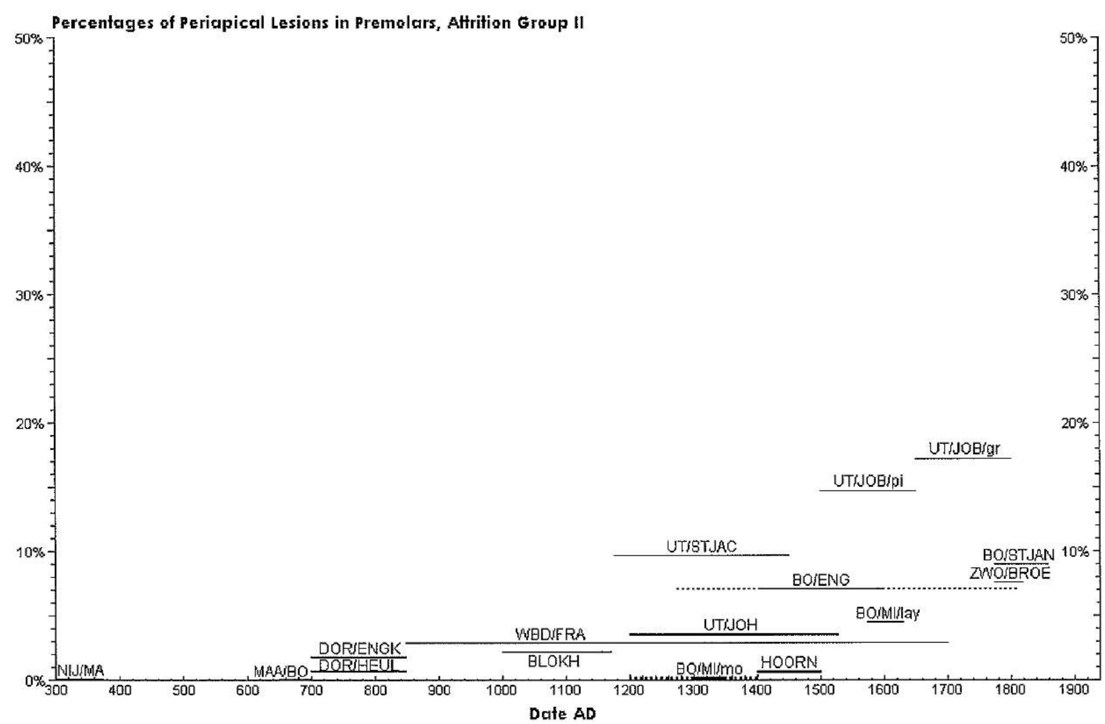

Figure 4: The percentages of periapical lesions in attrition group II premolars.

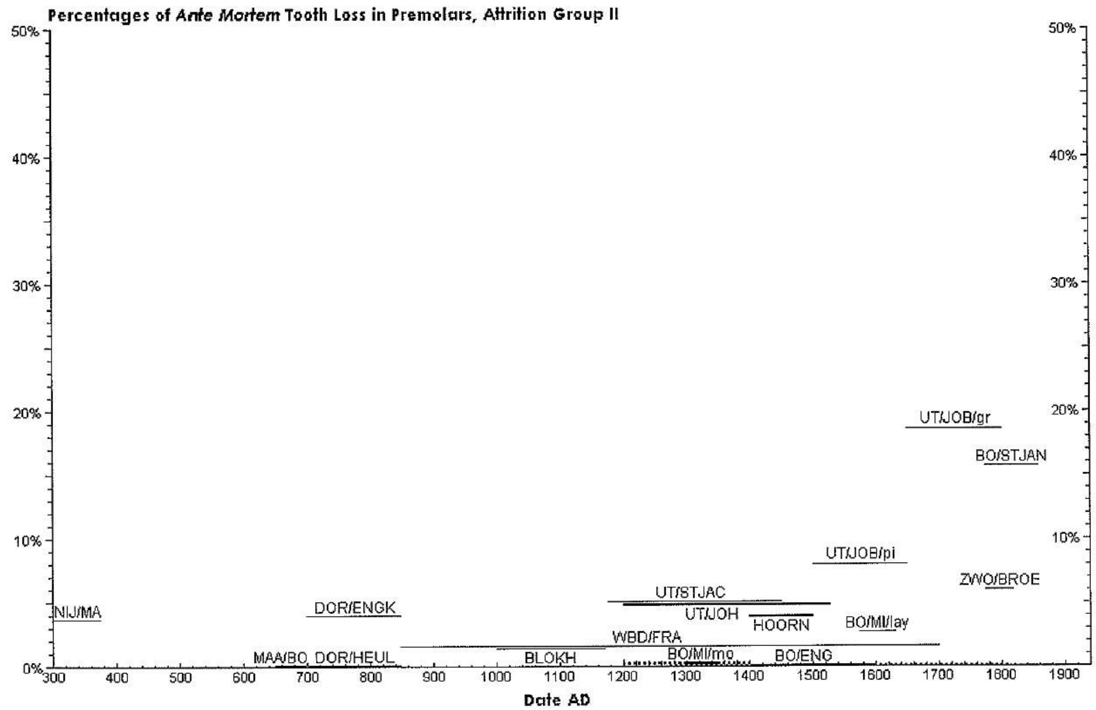

Figure 5: The percentages of *ante mortem* tooth loss in attrition group II premolars.

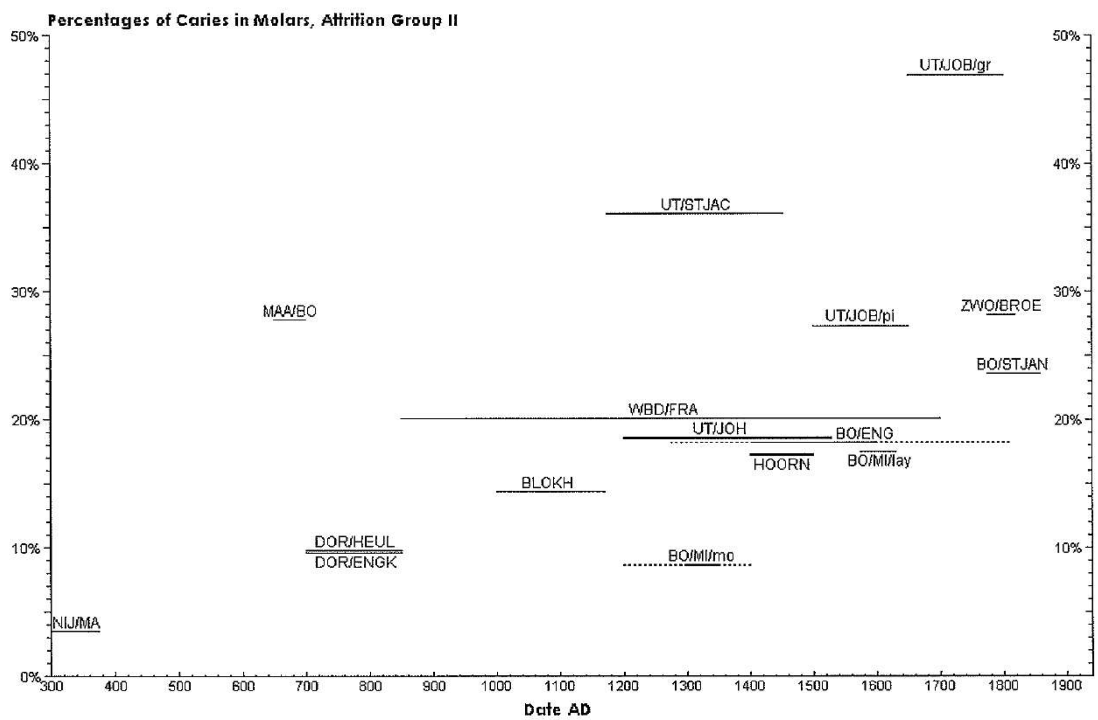

Figure 6: The percentages of caries in attrition group II molars.

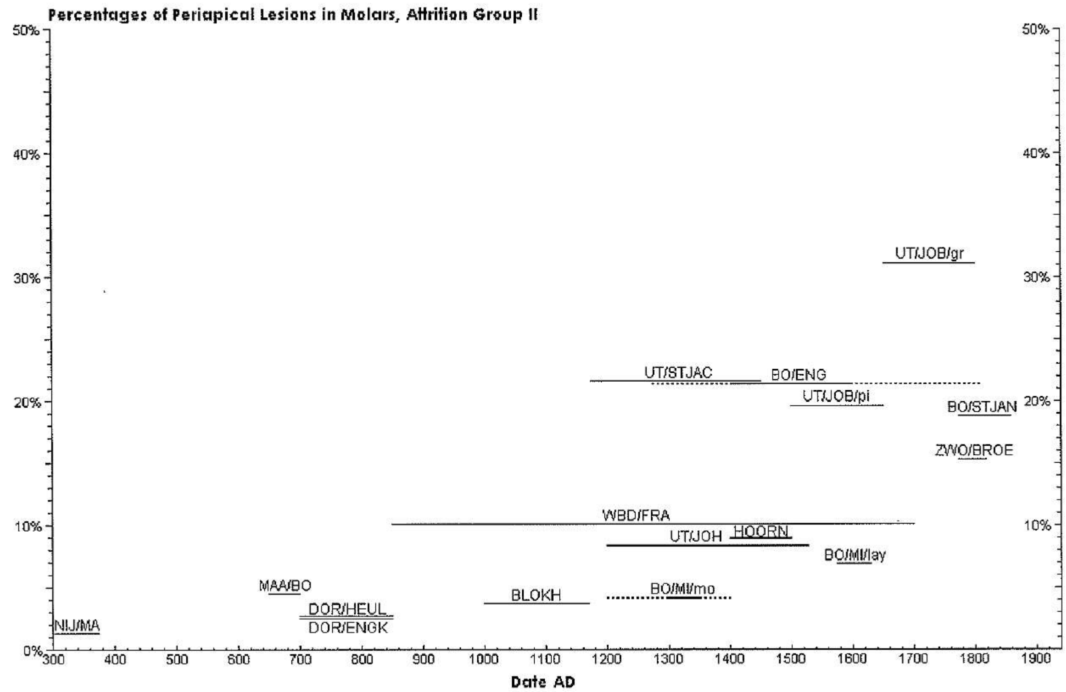

Figure 7: The percentages of periapical lesions in attrition group II molars.

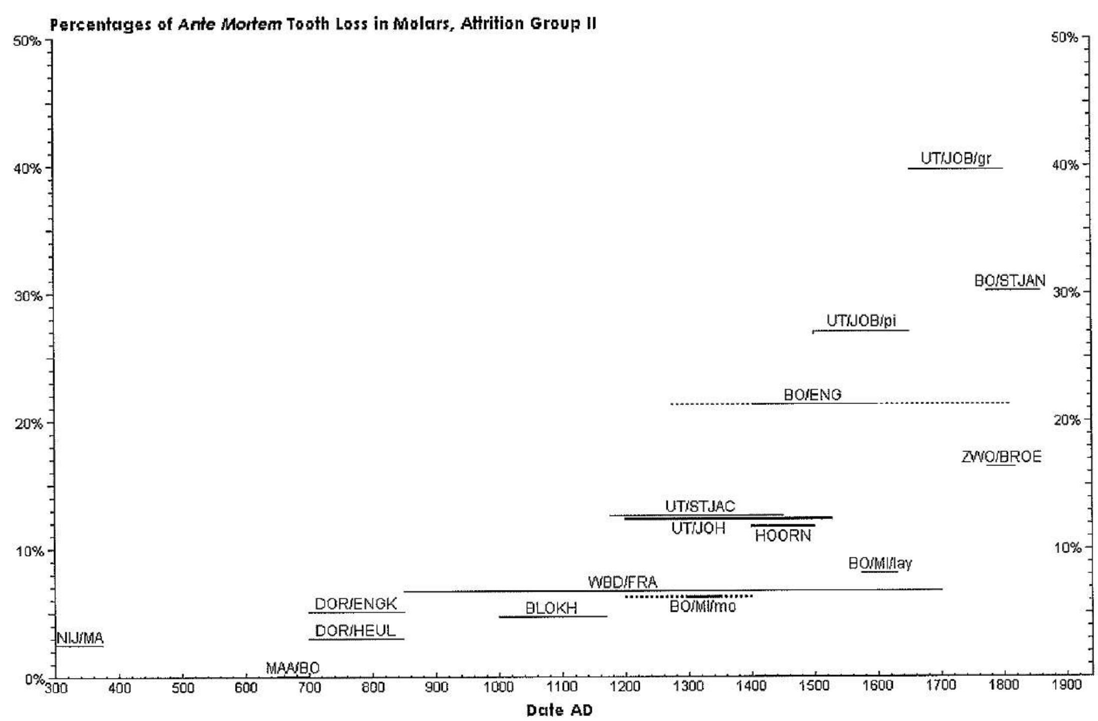

Figure 8: The percentages of *ante mortem* tooth loss in attrition group II molars.

In Figures 3 to 8, which illustrate teeth of individuals belonging to attrition group II in 16 dental samples, related to their date AD, some of the above significant results are visually presented including also the samples of longer duration. The three samples representing cloister populations are indicated by bold lines in each of Figures 3 to 8. The results for the premolars and molars in attrition group II were chosen for these presentations, because these form the best and most homogeneous representation of the samples in terms of age distributions and observability and because the differentiation between the samples is much clearer in attrition group II than it is in group I. The diagrams show the increase in dental pathology with time, however, not in the form of a more or less straight rising line but rather as a rising band, of which the width is increasing with time. The width of the band is due to the long dating spans of most of the samples on the one hand, and to hardly controllable variation between the samples on the other. Some systematic observations in the diagrams suggest that this latter variation is largely of a socio-economic nature. In the first place, the three samples where the inhabitants of cloisters are involved (B0/MJ/mo, UT/JOH and HOORN, indicated by the bold lines in Figures 3 to 8) are positioned in the lower part of the distributions for caries and periapical lesions (but not those for *ante mortem* loss). Although considerable differences in wealth between monastic orders have been reported (for The Netherlands *e.g.* by Burema 1953), in general the economic position of the monks and nuns may have been somewhat more favourable than that of the individuals in the other samples (*vide* also Caselitz 1998). Secondly, comparing contemporaneous samples, the Utrecht citizens of UT/STJAC generally show higher frequencies of lesions than do the well-to-do Johanniter monks, and the frequencies for the very poor individuals contained in the sample BO/STJAN are generally higher than those for the almost contemporaneous middle-class individuals in ZWO/BROE. The relatively high frequencies in the samples UT/JOB/pi and especially UT/JOB/gr may also be seen in terms of the low socio-economic position of the individuals which were nursed in the Sint Jobsgasthuis and in terms of the fact that they were living in a situation where the general level of disease and infection was probably very high. The above phenomena are also observed in many of the distributions for the other age/attrition groups and functional groups.

Conclusions

The results clearly demonstrate that the comparison of general percentages of dental pathology between samples, not differentiated as to age class. functional group and preferably sex, may yield unreliable results. They also show how part of these shortcomings, mainly those due to post-depositional processes, can be overcome, i.e. by first analyzing the distributions of the individuals within the samples as to age and preferably also sex, and the distributions of the dental elements and the alveolar locations in terms of functional groups and observability of caries, periapical lesions and *ante mortem* tooth loss.

Even when using such rigidly adapted analytical methods, the variability between samples is influenced by a large number of factors, of which chronology is only one. This is most clearly demonstrated by the wide variability between contemporaneous samples in our Figures 3 to 8. In addition to possible other, unknown, factors the depicted patterning strongly suggests that differences between the samples in socio-economic status, leading to differences in food consumption patterns and general health level, will have been the most important agents causing this variability. The figures further suggest that the differences in socio-economic status between contemporaneous groups increase over time. This agrees with the results of investigations of recent populations by *e.g*. Källestål & Wall (2002), Locker (2000) and Sheiham (1997).

Notwithstanding this variability and despite the complications created by the differences in the dating spans of the various samples, an overall increase of dental pathology with time could be demonstrated. This is in agreement with other investigations into this question (Caselitz 1998; Corbett & Moore 1976; Moore & Corbett 1971, 1973, 1975). Hillson (2003), citing the Moore and Corbett studies, depicts a steady increase of the percentages of elements with carious lesions in adult dentitions in Great Britain from the Saxon period up to the present time. In Caselitz 's study the incidence of caries in Europe (measured by the I-CE, the index of *caries et extractio*) is shown to be increasing, with some minor fluctuations, between the beginning of our era and the year 1950. Only around the year 1250 a sharper dip in the curve was observed. The periods of strongest increase were between *ca*. 150 BC and 650 AD and especially between *ca*. 1450 AD and 1950 AD. This largely fits with Caselitz's other curve, *i.e*. of the percentage of individuals showing caries in each sample. Also this percentage increases rather strongly up until *ca*. 600 AD, followed by a period of fluctuations. Around *ca*. 1300 AD the second increase slowly starts, but only around 1600 AD the levelof 600 AD was reached again. Unfortunately the data discussed in this study were not suitable to investigate in detail their agreement with Caselitz's findings. However, also our Figures 3 to 8 show that the increase of dental pathology is growing stronger from ca. 1200 AD onwards.

Obviously, the increase must be viewed in terms of changing dietary intake, especially the intake of different types of carbohydrates (starches from cereals, sugars, potatoes) and the frequency of their consumption. The decreasing fibre content of the diet has also played an important role (Hillson 2003). The changes in the dietary patterns were largely gradual with two more clearly defined moments of change: the first import of the new food products from the Americas after 1492, and the start of the production of beet sugar around 1753 AD in Europe (Caselitz 1998).

For The Netherlands Burema (1953) collected data on the changes in the regular diet of the various socialgroups from Medieval times up to the present. He stresses that during Medieval times the majority of the population was poor. Due to the limited intake of fruits and vegetables scurvy was a common disease, leading to loosening and loss of teeth. Main foodstuffs were bread and fish, and later also cooked cereals and coarse vegetables (turnips, carrots, onions, cabbage, *etc*.). Beer was a common beverage. During the 16th century the new products from the Americas were mainly available to the prosperous part of the population. The diet of the poorer classes showed relatively little change and scurvy remained a common disease. Especially in the hospitals for the poor the diet was rich in carbohydrates (cooked cereals) and lacking proteins, fruit and vegetables. During the 17th century the American foodstuffs slowly found their way to the poorer classes, but only during the 18th century potatoes became the most important component of the diet and were eaten two or even three times per day by the common man. During these last two centuries the practice of sieving the flour for baking bread became more and more common and during the 18th century the use of (beet) sugar strongly increased, as sweetener for cereals and beverages. During the 19th century these trends continued.

All the above is in agreement with the observed trends in dental pathology. The strong influence of socio-economic factors, suggested by Figures 3 to 8, and the increase in socio-economic differences as time went on, are also supported by Burema's observations on dietary differences between the social classes. Therefore these results corroborate those of other investigations into chronological trends in dental pathology in European countries.

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ENDNOTES

1. In addition to these 17 investigations, the dental material from the Late Mesolithic/Early Neolithic settlements at Swifterbant was studied by Pot (Perizonius & Pot unpublished a). This investigation has not been included in the present article. Also excluded was a study of l8-year old boys from Culemborg, Gelderland, The Netherlands. These boys showed caries on *ca.* 85% of their molars and premolars (Kwant *et al.*1974). Further manuscripts which should be mentioned here are Perizonius & Pot (unpublished b), Constandse-Westermann & Bouts (in press) and Constandse-Westermann *et al.* (unpublished). All but one of these manuscripts are available on request for the interested reader.

2. All data on which this study is based are on file and available on request from the authors. These data are: observability of caries, periapical lesions and *ante mortem* tooth loss per attrition group and per functional group for 14 of the 17 samples, the frequencies of these three categories of dental pathology, per functional group, in all four attrition groups for 16 samples and the frequencies of the three categories of dental pathology, in molars plus premolars, in all four attrition groups, in 17 samples.

3. For six of the samples the percentages of individuals showing enamel hypoplasia were established. However, such a percentage is dependent upon the preservation value of the dental elements in the sample in question, because the presence/absence of hypoplasia can only be established reliably for individuals of which all dental elements can be inspected. The preservation values of the dental elements in the more or less contemporary and geographically close samples UT/STJA and UT/JOH are almost similar (Pot & de Groot 1989). Furthermore, the dentitions in ZWO/BROE and BO/STJAN, which are also more or less contemporary, had almost similar numbers of preserved teeth and are therefore mutually comparable in this respect (*vide* Table 4). The samples UT/JOB/pi and UT/JOB/gr, on the other hand, showed large mutual differences in their preservation, which also differed from that of the four above dental populations. Therefore the percentages of hypoplasia in these last two samples have not been used in this study.

4. The detai1s of our procedures for the determination of the preservation value and for scoring dental pathology are available on request from the authors.

5. The exact methodology followed by Pot is available on request from the authors.

6. The percentages per functional group and per attrition group have been tested by comparing the frequency of occurrence of the observed overall sequence (observability of caries < observability of periapical lesions < observability of *ante mortem* tooth loss) with the liability that

this sequence would occur by chance (two-sample Chi-Square tests, Newell 1995; Siegel 1964). The same procedure has been applied in the tests of the observability differences between the attrition groups.

7. All test results are available on request from the authors.

8. The material of the 17th sample, LENT, has been described in Perizonius & Pot (unpublished b). Unfortunately, this manuscript in not any more available. Therefore, the only disposable data were the percentages of caries, periapical lesions and *ante mortem* tooth loss in the molars plus premolars. In order to investigate the relation between LENT and the 16 other samples, the percentages for molars plus premolars were calculated also for the latter 16 and all tests were repeated (Spearman Rank Correlations, Newell 1995; Siegel 1964), including LENT in the sequences. The levels of significance were almost similar: the 16 samples yielded 20 significant correlations of 27 tests, including LENT seven significant results were obtained out of nine tests.