Computerized recording and analysis of excavated human dental remains.

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COMPUTERISED RECORDING AND ANALYSIS OF EXCAVATED HUMAN DENTAL REMAINS

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Introduction

Each excavated human dentition can be considered as a personal archive. It contains information on endogenous and exogenous processes whose effects accumulated during life. These can be read and interpreted. The information which can be retrieved from the dentition pertains to two periods:

A. THE PREFUNCTIONAL PERIOD : (PRE-)ERUPTIVE INFORMATION

<u>Physiological</u>	<u>Pathological</u>
-morphology	-developmental disturbances
-developmental stage	-eruptive disturbances

a. of the jaws
b. of the teeth

B. THE FUNCTIONAL PERIOD : POST-ERUPTIVE INFORMATION

<u>Physiological</u>	<u>Pathological</u>
-attrition	-caries
-occlusal, proximal	-peri-apical bone lesion
-alveolar resorption	-antemortem tooth loss
	-alveolar resorption
	-trauma (abrasion, fracture)
	-dental calculus

The primary task of palaeo-odontological research is to extract the above data from the excavated human dentitions, to interpret them and to present these interpretations in a meaningful manner to the archaeologist. The data represent the interaction between the (growing) dentition on the one hand, and on the other exogenous biological, biochemical and mechanical factors of wear and deterioration. Seen in the light of this dynamic equilibrium they contribute to a better understanding of everyday life, feeding patterns, and activities in which the dentition is used. Moreover, they can give information on the age at death of the individuals and thus on the demography of ancient populations.

For this purpose, the original data as well as their interpretations must be made accessible. However, the large amount of dental material which can be produced by excavation is difficult to handle and to analyse in a standardised manner. The expertise of highly specialised scientists is required to evaluate the dentitions and the skeletal remains. Statistical analysis of the data is often time-consuming; it is necessary to extract the data from their records and to rearrange them, introducing amongst others the risk of errors and inconsistencies. Moreover, differences in method between the various scientists often preclude comparisons between their respective results.

The use of automated database systems for this type of research would offer new opportunities for more elaborate analyses and comparisons, while maintaining direct control over the original data records. If the registration and recording of the primary skeletal data is performed by a trained scientist, their subsequent analysis can be performed in co-operation with a statistician and the archaeologist. In this way, a true multidisciplinary approach is realised.

Automated registration

As a first step in this direction, the graphical registration of dental data was introduced (Perizonius and Pot, 1981). To facilitate a detailed recording of the existing teeth and jaw bone, and to score physiological and pathological phenomena, a dental data form was designed. On this form, caries, attrition and periapical bone lesions can be recorded by pictograms, numbers and symbols. In this way the general dental status of each individual can be appreciated at first glance. However, the completion of such a form proved to be a laborious and tedious task, and for publication, the entire form had to be redrawn by a skilled graphical artist.

In addition, this method does not solve the above mentioned problems of data retraction for statistical analysis and mutual comparability of the applied methods.

For an efficient registration and recording, a combination of the graphical forms and a database system should be used. With the original data form in mind, a new one was designed, which would allow automatic registration of the visualised data in an alphanumerical database (Figure 1). For this purpose, a graphical programme was developed, which acts as a bi-directional translator of the graphical input and the appropriate codes in the database. The programme, intended for use on IBM-PC/XT/AT and true compatibles, is written in Turbo Pascal 4.0, occupies about 260K of memory, and is compatible with the various graphical standards currently available. A demonstration version, without the database facilities, can be delivered upon request.

The programme enables the researcher to record the data from the jaws and teeth in a way which closely resembles the earlier designed form and adds extra possibilities for automated selection and other database functions, as well as the automated production of camera-ready forms. To achieve this goal, the input of data is based on a graphical representation as it was in the hand-completed form (Figures 1 and 2).

Several alterations, necessary for automated processing of the data are introduced in the new form. As a result of these modifications the number of registrable qualifications is increased. Most of the symbols

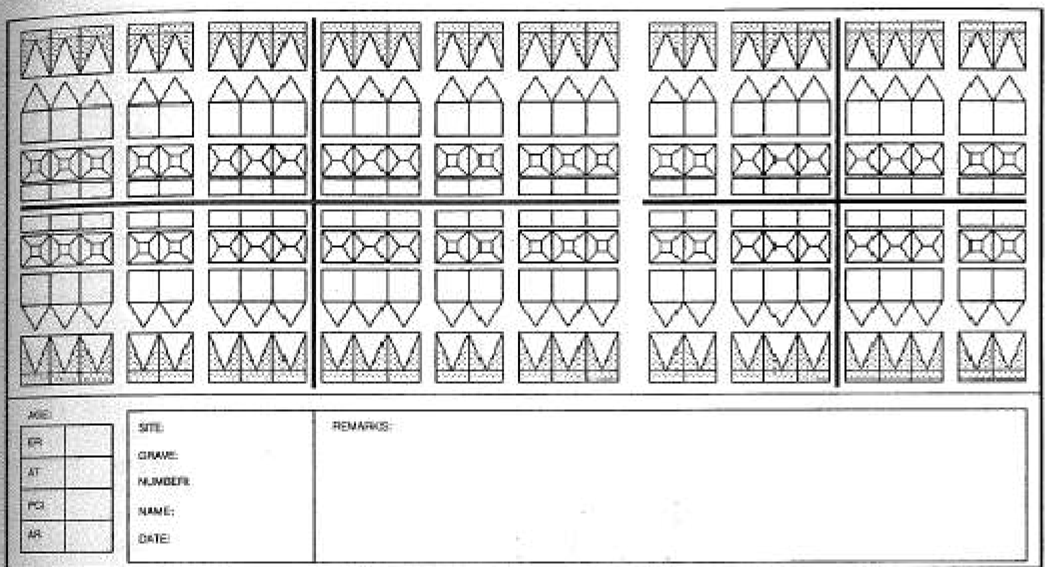


Figure 1 The blank form for the registration of both the deciduous and the permanent dentition; as it appears on the screen. In the lower left column the characteristics can be indicated on which the age determination is based (eruption, attrition, PC1-index (see below) or alveolar resorption).

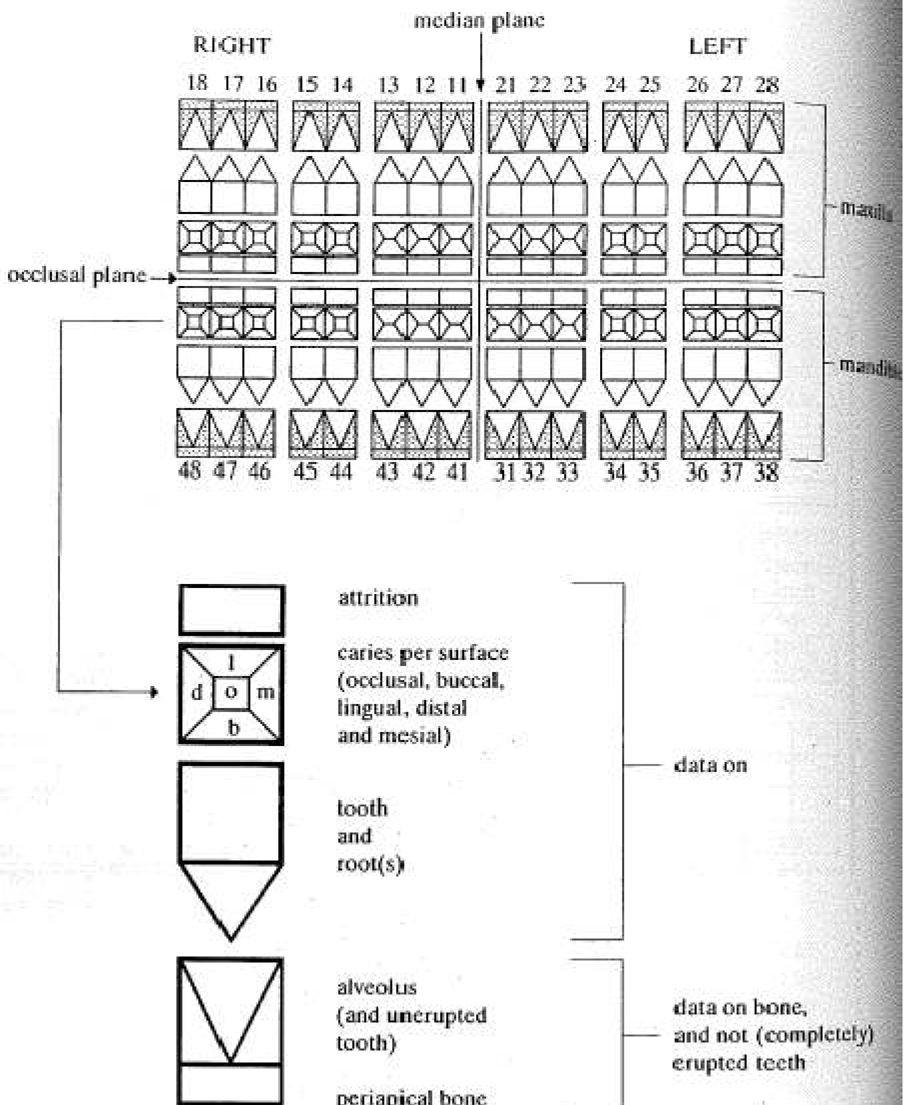


Figure 2 The key to the dental registration form.

were left as they were, but the possibility of inserting data on calculus, and extra space for a separate recording of data on tooth roots and unerupted elements have been added. As an additional effect this produced the opportunity to record the alveolus in a visually more understandable way. Furthermore, the possibility was included to record extra data for every individual tooth. This special data option provides the opportunity to add new classifications to the database which are not incorporated in the standard programme e.g. the manifestation of man-made artefacts, anomalies, non-metrical traits, alveolar resorption, fissure patterns etc. The presence of such extra data is indicated on the form by a star in the crown of the tooth. For the standard registration of attrition, important for the estimation of age, the currently selected attrition is shown graphically. The symbols for filling out the registration form are presented in Figure 3.

For easy control of the data entry, a mouse based input routine was developed which was combined with a menu structure for guiding the operator through all possible combinations. Error checking for inconsistencies is incorporated, preventing the production of contradictory records.

The basis for the grouping of each series of excavated dentitions is their common place of excavation. All dentitions from one site are stored within a separate database in which each dentition is identified by a unique number. The programme checks the database for double entries and refuses to continue in such a case. After a valid number has been entered, the operator can opt for the presence or absence of the deciduous dentition in the current specimen. When this choice has been made, data entry can start by selection of the individual dental elements, either by cursor control from the keyboard or by mouse selection. The element of choice is selected and copied onto a work area. At this stage, the operator can select several options: tooth data, bone data and extra data. Once a selection has been made, the next level of the menu is displayed, which now shows the various types of data which can be recorded (Figure 4).

All options can be selected by the cursor or by mouse movements from the individual menus. They can also be entered directly from the keyboard. Data are stored internally in a temporary buffer, which can be written into the database using the file utility menu. The database format is either a compressed internal format for optimal disk space preservation, or a dBase III compatible ASCII file format for external use of the database contents. Routines for conversion between both formats are provided.

Additional information on every dentition can be stored in a note which cannot be used for indexing the database. After the dentition data have been stored in a file, the file can be viewed on the basis of the identification numbers, or sequentially, by manual control of the pages. The entries in the database can be marked and copied into a new file, thus enabling the operator to make manual selections of the registered dentitions.

data on erupted teeth

Data on bone and not (completely) erupted teeth

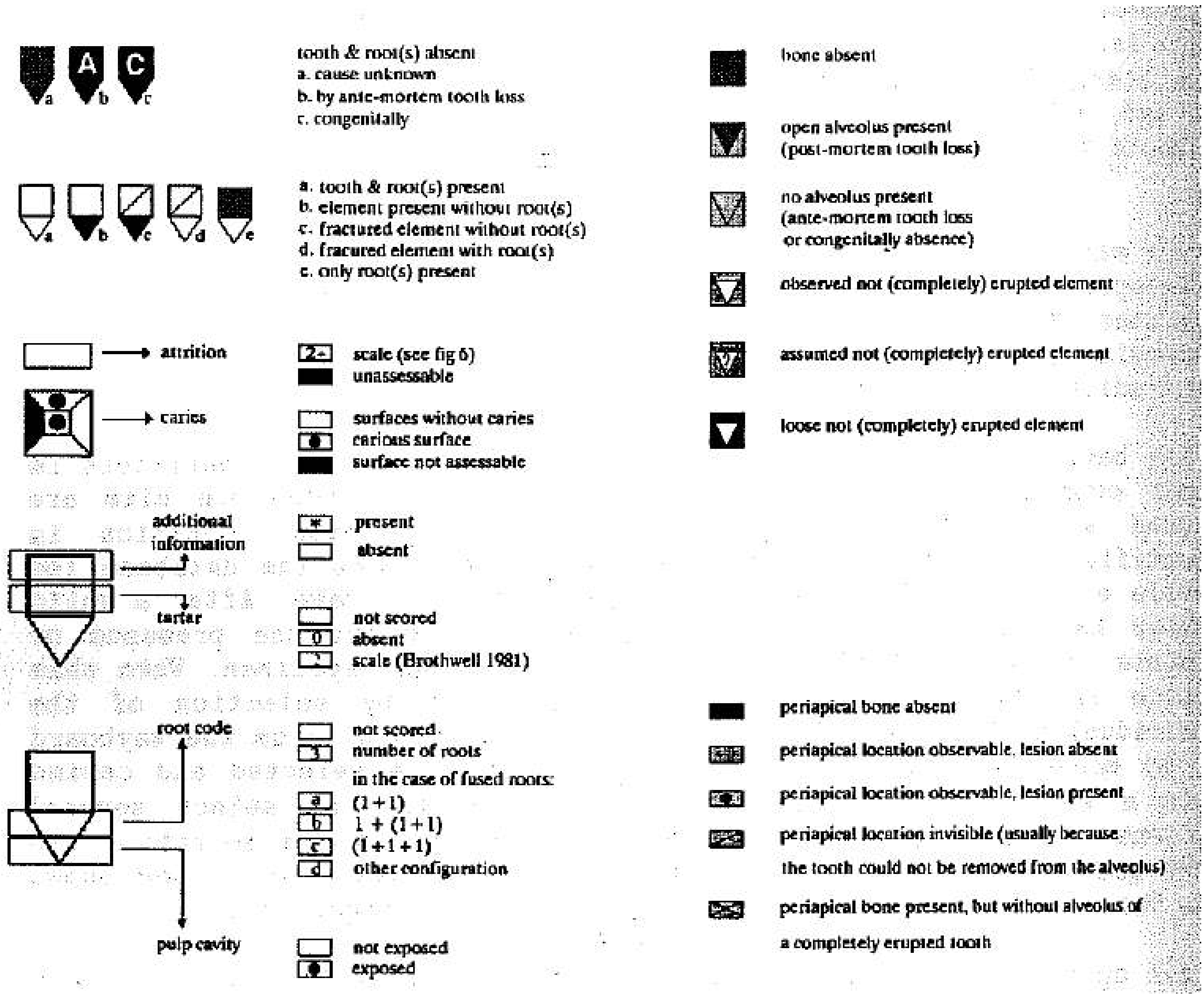


Figure 3. The picture-symbols for filling out the registration form.

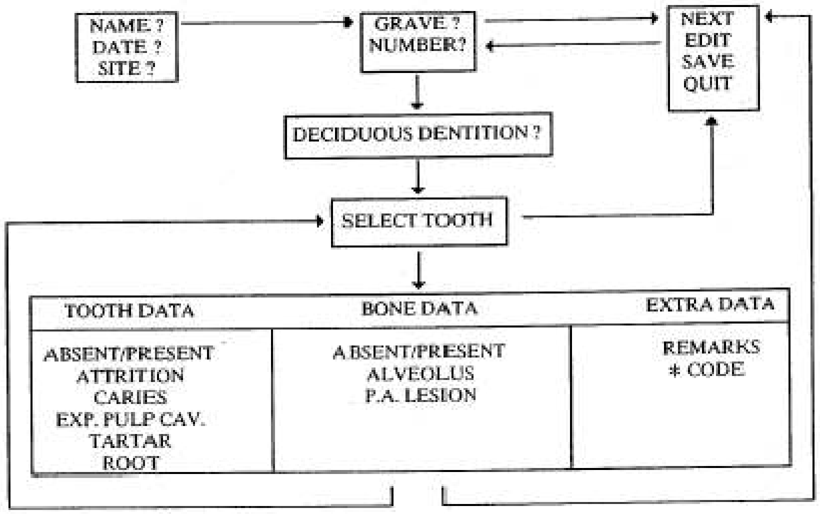


Figure 4. Flow chart of the registration procedure.

Statistical and graphical possibilities

The dBase III compatible ASCII file format enables the user to enter data from the file into most current statistical and graphical computer programmes e.g. SPSSPC+, SAS, LOTUS, Harvard Graphics, Microsoft Chart etc. In this way the analysis and mutual comparison of large dental samples becomes possible. In Figure 5 an example is given of the kind of graphical representation which can be obtained directly from the data file.

Method

a. General

It is important to record both the presence and the absence of the teeth and the jaw bone as well as all other detailed information regarding the state of the individual teeth and the alveoli. This gives immediate information about the tooth loss which took place post-depositionally (postmortem tooth loss).

In this way the frequencies of the phenomena caries, exposed pulp cavities, periapical bone lesions, attrition etc. can be reliably computed. The scoring of the principal characteristics of the teeth and the jaw bone results in primary data, from which conclusions can be drawn regarding diet, age and particular habits and uses.

In the following section the standards will be described for scoring attrition, caries, peri-apical bone lesion and dental calculus in order to obtain a uniform system. In the subsequent paragraph the interpretation of the collected data in terms of age estimation will be explained.

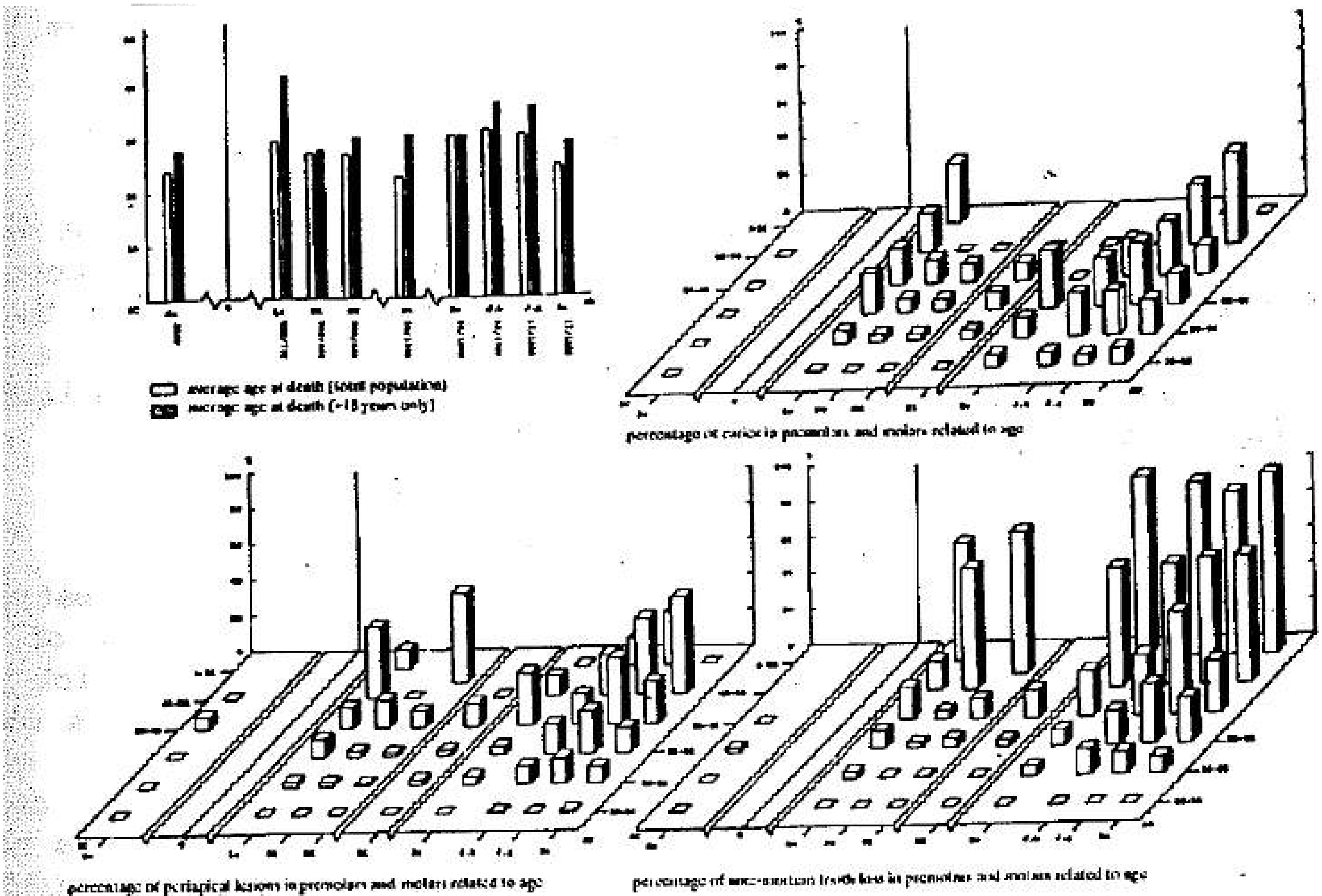
b. Attrition

At a certain time the erupting teeth (or elements) will meet their antagonists and finally the complete dentition is arranged into occlusion.

As a result of mastication the teeth will start to wear down. Under normal circumstances this is a continuous and progressive process and the amount of attrition can be viewed as a reflection of the extent of the functional period of the tooth.

When an excessively high rate of attrition is observed for one (or a few) specific element(s), usually an exogenous cause other than mastication can be suggested. In such a case the phenomenon is called abrasion. An excessively low rate of attrition, on the other hand, is the result of disturbances in the articulation initiated by for example, painful caries, inflammation, antemortem tooth loss etc. In the latter case the attrition process is disturbed or completed.

Brothwell (1981) designed a method for scoring attrition which is based on his investigation of Neolithic to Medieval British skulls. However, in this system, which is widely used, only molar attrition is



LINK to enlarged version of Figure 5 with key to sites.

Figure 5 Graphical representation of the data which can be retracted from the database: some comparisons between Dutch populations ranging from 3300 BC to 1850 AD (in diachronical order).

taken into consideration. Therefore, the authors added attrition classifications for the other dental elements into our new scheme (Figure 6). In case the molars cannot be used this will prove to be important in relation to age estimation. (see below).

c. Unerupted elements

In erupting dentitions a number of the elements which are not yet in occlusion can already be observed in the jaw. These are scored as being present and erupting. Tooth germs whose presence within the jaw bone can be noted as present, but not assessed visually using a probe or by X-ray investigation, are scored as unassessible. Unless there is a clear indication of absence they are assumed to be present.

d. Caries

The disease of dental caries is the result of a demineralisation of the tooth substance. This process is due to the effects of acid produced by different types of bacteria from carbohydrates which occur in the dental plaque. Caries develops on specific locations on the tooth i.e. those places where food retention usually occurs (predilection sites). Therefore various types of caries can be distinguished. Occlusal caries occurs in the fissures and pits of the occlusal surfaces of molars and premolars. Cervical caries is found at the gingival margins. The third type, approximal caries, is initiated on the contact areas of adjacent teeth.

Morphological and functional differences between the various dental elements are causes of differences in caries susceptibility between them. A comprehensive study of this structural phenomenon is in progress.

Dental caries manifests itself in several ways. Initial lesions present themselves as merely opaque white spots in the still intact enamel surface (Pot *et al.*, 1977). Postmortem decomposition while in soil can result in features which are very difficult to distinguish from initial caries.

In the course of the continuing carious process, these sub-surface lesions will result in the formation of a cavity with a discontinuity in the enamel surface.

Caries can be scored per element and per predilection site as being either present or absent. Because of the above possible confusion with postmortem decomposition we advise scoring only clear cavities which have obviously originated at predilection sites. In the case of incipient carious lesions, when decalcification has started but there has been no formation of cavities, caries should be scored as absent.

e. Exposed pulp cavities and periapical lesions

Bacterial infection of the tissues in the pulp cavity of a tooth can be seen as the result of a deep carious process, excessive attrition or trauma. Once the bacteria succeed in penetrating into the pulp cavity,

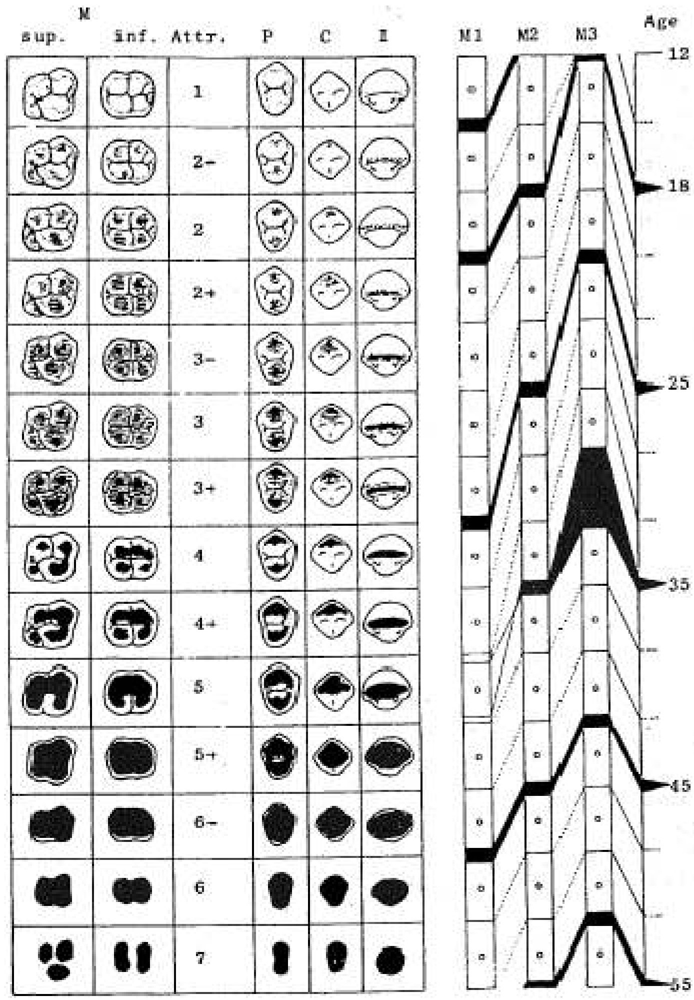


Figure 6. The attritional scale in relation to age. The recorded rate of attrition must be connected horizontally to the particular molar on which it has been observed. From thereon the diagonal paths indicate the most probable age at death of the individual. Attrition evaluations pertaining to the premolars, canines and incisors can be used to calculate the PCI - index.

the inflammation spreads rapidly towards the apex of the root. Here it may affect the surrounding jaw bone, resulting in an expanding globular cavity in the bone around the apex. If the process continues for some time, the cavity may reach the surface of the jaw bone where it forms a fistula.

Theoretically, both exposed pulp cavities and periapical lesions should be scored as being either present or absent. However, when there is no fistula, the only way to detect a periapical lesion without the use of X-rays is to remove the tooth and to inspect the alveolus visually or with help of a dental probe. Therefore, when a tooth cannot be removed from the alveolus the status of the jaw bone has to be recorded as unassessible.

When only an isolated tooth is available, the presence or absence of a periapical lesion can be evaluated by examining the possible presence of an exposed pulp cavity in the tooth. An exception to the above are the rather uncommon periapical lesions which result from periodontal infection. In this case the apex becomes directly infected and not via the pulp cavity.

f. Dental calculus

When high pH phases predominate in the mouth dental plaque can start to mineralise. The mineralisation product, dental calculus, is commonly known as tartar. The extent of these deposits can be scored on a simple scale according to Brothwell (1981). Recently, Dobney and Brothwell (1987) published a new scoring system for dental calculus which is, however, rather complicated and therefore only suitable for highly specialised studies.

g. Antemortem tooth loss

Periapical processes, alveolar resorption or trauma can be seen as the major causes of antemortem tooth loss. Once the tooth is lost, remodelling of the jaw bone will start to fill up the empty alveolus. This renders it rather easy to differentiate between antemortem and postmortem tooth loss, the latter process resulting in an open alveolus with sharp contours.

In addition the assessment (present or absent) of antemortem tooth loss cannot in all instances be made with certainty. In a number of cases a distinction between the congenital absence of the dental element (see below) and the presence of an underlying, but not yet visible tooth-germ can only be made by X-ray investigation. In those cases the cause of the apparent absence of the element should be scored as unknown.

h. Congenital absence

In some cases the germ of a certain element has never been formed in the jaw bone. This is called congenital absence; this condition can only be assessed with certainty by X-ray investigation.

Age estimation

Both dental eruption and dental attrition are sources of information pertaining to the age at death of the individual. They are mutually complementary, eruption providing information about the pre-functional period, while the information derived from attrition pertaining to the functional period.

The subsequent developmental stages of the dentition occur consistently in most individuals of the same species (Hillson, 1986). However, a certain variation in the relationship between biological and chronological age exists between populations and even between individuals within each population. Therefore age estimations based on dental development represent the dental (developmental) age, rather than the actual chronological age of the individual.

Nevertheless, the eruption stage can be used as an indicator for the age of young individuals. Ubelaker (1984) presents a scheme for the sequence of formation and eruption of the teeth which can be used as a reference when applying this method. The scheme provides information about the moment at which each tooth comes into function.

Attrition also provides information on the age at death of an individual. In this case the information is not based on its biological development. Instead the method uses the time length during which every tooth was in use for mastication and perhaps other purposes, i.e. exogenous factors. This causes the results to be more subject to random variation than in the case of eruption.

Although the technique applies to all elements, the permanent molars are the most suitable. Both their morphology and their specific function (as main masticators) result in a clear picture of the occlusal plane of the attrition which has occurred. They have no predecessors in the deciduous dentition, resulting in a very regular eruption pattern. This provides the possibility to calibrate the attrition scale for each specific population (Miles, 1963). The three molars erupt at intervals of approximately six years, starting with the first molar at the age of six. This implies that the differences in attrition between these three elements reflect a period of six years of wear.

The chronological relationship between the wear of the various molars makes it possible to estimate for each population (and theoretically even for each individual) the pace with which the attrition process has proceeded. All age estimations on the basis of this attribute should be viewed within the light of this approximate pace of the attrition in the populations in question. It is dependent on the individual's feeding patterns and the specific use which may have been made of the dentition etc. In future research the authors will attempt to design a method to adapt the age categories in Figure 6 with reference to the average attrition rate in the material studied.

The M1, being the first molar to erupt, is more likely to be affected by disease, for example caries, than the others, resulting in the risk of an early loss of the element. The M3 is the most variable between individuals in its presence or absence, morphology and eruption time. It is therefore also less suitable as a generally applicable element for age estimations on the basis of attrition.

As a consequence, the 2nd molar is the preferred element for this purpose. Age estimations are best based on the mean of the individual attrition rates of the 2nd molars. However, these may be absent or not possible to use, or because their degree of attrition is anomalously high or low (see above under attrition) or because they are broken or carious. In such a case the other molars have to be used (Figure 6).

In this stage of the research it is not possible to define exactly the conditions for the use of either the M2 or the other molars, or how the choice between using M1 or M3 should be made. Furthermore, not all attrition stages could be defined precisely around the 35 years age category. One of our research projects is a reappraisal of the age categories in the scheme using a collection of skeletons of known age and sex, recently excavated in the Netherlands.

Using the scheme of Brothwell, or using our own scheme but limiting the assessment of the attrition rate to the molars, renders a serious bias to the age estimations. More specifically, the absence of all molars, as well as an abnormal attrition pattern of these elements, would imply the elimination of the individual from the age sample. As a result, this would lead to selective exclusion of the older individuals from the age sample because, more specifically, these people are liable to have lost one or several molars in life. Moreover, the older individuals have the highest attrition rates, leading to open pulp cavities and periapical lesions. Both biases would lead to a reduction of the estimated mean age of the sample.

In view of the above the original scheme was expanded to include the incisors, canines and premolars (Figure 6). The degree of attrition of these elements is summed and averaged to calculate the so-called *PCI-index* (Pot, 1988). This index allows an age estimation in those cases where the molars are absent or cannot be used due to abnormal circumstances. To this end the PCI-index value of all individuals with complete dentitions in the populaion is determined and related to their 'M2 age'. From these data the average 'M2 age' per PCI class can be determined. These average 'M2 ages' give an indication of the age of the individuals in the respective PCI classes, which can be used for the specimens with incomplete dentitions i.e. lacking molars.

The above method shows that both dental eruption and attrition are important indicators of the individual age at death. However, they should always be evaluated in relation to the complete picture provided by all dental data of the individual in question. This implies that no reliable age estimation can be based on the attrition figure of a loose tooth, where there is no information on, for example, the presence or absence or the pathological condition of its antagonist or its neighbours.

The complete picture represents the frozen stage of the dynamic process of dental development and decay at the time of death and it is only in relation to that setting that an attrition figure for an individual tooth can be correctly evaluated.

Conclusions and future research

The automated registration of dental data provide improved possibilities for their efficient and accurate analysis. A number of Dutch populations, ranging from 3300 BC to 1850 AD have already been examined. An example of the results of that analysis is presented in Figure 5. A future publication will be dedicated to the statistical analysis of those results. An attempt will be made to establish the presence or absence of systematic differences in caries susceptibility between the various (groups of) elements. Moreover, an attempt will be made to quantify the reliability of age estimations; that reliability is dependent upon the (im)possibility of making observations on the various (groups of) elements and upon their presence or absence in the excavated dentitions. Furthermore, there is a plan to investigate the possibility of defining a uniform scoring procedure in the case of absence of the most informative dental elements (the 2nd molars) and of designing a method to adapt the age estimations with reference to the average pace of the attrition process in a specific population. Finally, by using a recently excavated Dutch sample with known age and sex, the age categories will be reassessed in the scheme of Figure 6.

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