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Age Estimation Using Destructive and Non-Destructive Forensic Dental Methods on an Archeological Human Sample from a 16th - 18th Century Nunnery in Brussels, Belgium

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Abstract

Introduction: Dental age estimation can be performed both in living and deceased individuals. In archeology, few studies have tested the reliability of forensic dental age estimation methods complementary to the usually applied anthropological methods. Objectives: Destructive and non-destructive forensic dental age estimations were applied on an archeological sample in order to compare their consistency with earlier obtained anthropological age estimates.

Materials and Methods: One hundred and thirty four teeth from 24 archeological individuals were analyzed using Kvaal, Kvaal and Solheim, Bang and Ramm, Lamendin, Gustafson, Maples, Dalitz and Johanson's forensic dental age estimation methods. Results: The range of the forensic dental age estimates (point predictions) was wider than the age ranges obtained by the anthropologist. Furthermore, a high variability in the forensic dental age predictions could be observed in each subject.

Discussion: The wider variation observed comparing the forensic dental and the anthropological results are mainly due to the necessity to apply tooth position specific forensic dental methods in an archeological sample with incomplete dentitions and to diagenetic changes in the archeological collection.

Keywords: Forensic odontology; Dental age estimation; Archeology; Anthropologic age estimation

Abbreviations: CE: Common Era; FDI: Fédération Dentaire Internationale

Introduction

Identification of human remains and the estimation of their biological age are principal investigations in bioarchaeology and forensic sciences. In the former, the age of an individual is essential for further analysis of the demographic and adaptive characteristics of the studied population [1]. In the latter, age estimations are most important as part of human identification and in cases of living individuals without or with doubted age documentation [2]. Between 2004 and 2005, archaeological rescue excavations took place at the site of the former Poor Clare Nunnery in Brussels [3]. The nunnery was founded at the beginning of the 16th century of the Common Era (CE) and abandoned by the end of the 18th century CE. During the archaeological excavation, preceding the construction of an underground parking lot, 51 articulated skeletons were unearthed. The human remains pertaining to 48 adults (29 females, 15 males and 4 indeterminate individuals) and three sub-adults were examined using osteological sex and age estimation methods. Sex estimation was based on the morphological characteristics of the cranium, mandible and pelvis Ferembach, et al. [4] & Quintelier et al. [5]. Age estimation was primarily based on degenerative changes of the pubic symphysis and the auricular surface of the ilium Lovejoy, Suchey, Brooks, Quintelier et al. [5-8]. Dental wear, cranial suture closure, degenerative changes at the sternal end of the 4th rib were only carried out as supplementary age estimation techniques Hunger, İşcan, Quintelier et al. [7,9,10] & Maat [11]. No dental age estimation had been conducted by the anthropologists.

Different forensic dental age estimation methods have been developed to estimate the age from pre-natal to adult. In children and sub-adults, dental development has been studied and documented. In adults, morphological changes in teeth were the main studied variables [12]. They have advantages in terms of simplicity, cost and time and can easily be applied on archeological samples [13-20] Kvaal et al. [21]. All existing forensic dental age estimation methods provide an estimated age (point prediction) and most of them report a related measure of uncertainty [22].

The aim of this study was to apply different forensic dental age estimation methods on the Poor Clare Nunnery collection and to compare the uniformity between the obtained dental age estimations and earlier obtained anthropological age estimates [23,24].

Materials and Methods

The skeletal remains of 24 individuals from the post-medieval Poor Clare Nunnery in Brussels were retained for study based on the presence of either premolars, canines or incisors. This material belongs to the Heritage Service of the Brussels Capital Region, where it is stored. For the data collection it was allowed to photograph and radiograph all teeth, to extract maximum seven teeth per individual and to cut one extracted tooth from each studied subject. The extracted teeth were kept in individually labeled bags and returned to the respective skeleton after examination. The present study received approval by the Ethics Committee of the University Hospitals Leuven on November 24th, 2015.

Table 1: Number of subjects evaluated and analyzed teeth per used forensic dental age estimation method

Method	Number of subjects	Number of analyzed teeth	Number of clinical measurements
Kvaal et al. [21]	22	71	639
Kvaal and Solheim [20]	22	120	480
Bang and Ramm [15]	23	117	140
Lamendin et al. [18]	24	95	285
Gustafson [13]	24	24	144
Maples [17]	24	72	432
Dalitz [14]	16	16	64
Johanson [16]	24	24	144

One hundred and thirty four teeth were extracted, i.e. 56 incisors, 27 canines, 23 first premolars and 28 second premolars. Teeth with extensive caries compromising the pulp or with cracks through the enamel complicating the radiographical analyses were not selected. Teeth with hypercementosis, interfering with the morphological analysis, were also excluded. On each extracted tooth, the corresponding tooth position specific forensic dental age estimation methods described in the respective following publications were applied: [13-18,20] Kvaal et al. [21] (Table 1). During the tooth selection, priority was given to upper central incisors since they were described by three different authors as better age predictors compared to the other teeth [18, 19,21].

From each extracted tooth, bucco-lingual periapical radiographs were taken using a NOMAD® (Aribex Inc., Orem, Utah, USA) portable unit. A fixed output of 60kV was used and the exposure time varied from 0.18 to 0.20 seconds, depending on the tooth type. Each tooth was attached to the Sigma M sensor (Aribex Inc., Orem, Utah, USA) using transparent tape and then radiographed mimicking the parallel technique. The images were captured and processed using Cliniview® software (Instrumentarium Dental, Tuusula, Finland) and exported in .jpg format for further analysis.

Two groups of data were collected: the first on intact and the second on sectioned teeth. On the intact teeth, radiographical and clinical measurements were established according to Kvaal et al. [21] (Figure 1). The radiographical measurements were performed after importing the radiographs in ADOBE Photoshop C5® (Adobe systems, San José, California, USA).

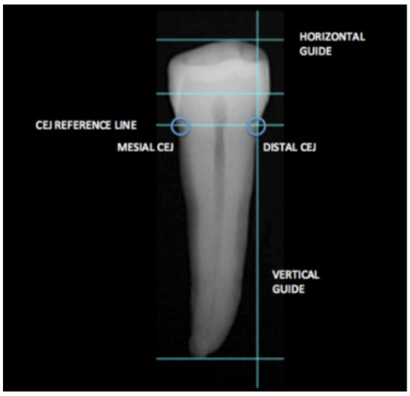

Figure 1: Landmark placement for radiographical measurements in ADOBE Photoshop C5®.

Each tooth was oriented using the cemento enamel junction (CEJ) as landmarks. A line was drawn from the mesial CEJ to the distal CEJ. The tooth was then rotated to make that line the horizontal. Subsequently, guides were dragged to the desired landmarks and the distance between them was measured. This information was recoded and integrated in the correspondent formulas proposed by Kvaal et al. [21] and Kvaal and Solheim [20,19].

The 24 sectioned teeth were cut longitudinally, using a hand piece and a dental stone grinder, described as the half tooth technique by [25]. The obtained sectioned teeth were photographed at the cut side together with a millimeter grid on a transparent layer, using a Dino-Lite® digital microscope (AnMo Electronics Corp., New Taipei City, Taiwan).

The anthropological age estimations were reported as the 5, 10, or 20 years age range or the age range older than 40, 50 or 60 years, the obtained osteological point estimates were fitting in respectively (Table 2). When an age estimation method required implementing the subjects sex the anthropological sex estimates were used.

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Table 2: Number of subjects per estimated anthropological age category.

Estimated age at death range in years	Number of Subjects
15-20	1
20-25	1
20-30	2
25-30	1
25-35	1
30-35	1
30-40	4
40-60	4
40+	2
50+	4
60+	3

The point estimates of the forensic dental age estimation methods and their mean were calculated and compared with the anthropological age ranges in four groups: per subject, per applied forensic dental age estimation method, per tooth position, per tooth type. Descriptive statistics were used to compare the forensic dental and anthropological age estimations.

Results

Five hundred and thirty nine data registrations were performed on 133 teeth. Not all subjects had the same number of teeth qualifying for inclusion, nor were all qualifying teeth in a condition that allowed to apply the age estimation methods. The number of teeth analyzed per applied forensic dental age estimation method was reported in (Table 1). The number of data registered on the different tooth positions (Fédération Dentaire Internationale (FDI) tooth numbering system) was shown in (Table 3).

Table 3: Number of subjects analyzed and data registrations per tooth type.

Tooth #	Number of subjects	Number of data registrations	Tooth #	Number of subjects	Number of data registrations
11	10	79	21	12	100
12	6	24	22	3	6
13	6	15	23	5	14
14	1	4	24	3	12
15	13	55	25	7	36
31	4	16	41	5	15
32	8	34	42	7	23
33	10	22	43	6	19
34	9	26	44	10	67
35	4	16	45	4	14

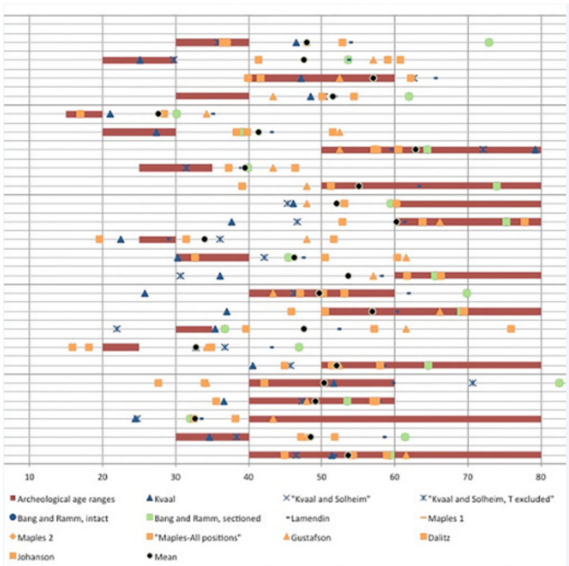

Figure 2: Forensic dental age estimates (point predictions) and anthropological age estimate range per subject. The red bars represent the age-at-death range given by the anthropologist. The colored figures represent the different point predictions from the applied forensic dental age estimation methods. Blue: non-destructive methods; Orange: destructive methods; Green: combined destructive and non-destructive methods; Black: point predictions of forensic dental age estimations (Mean). Both anthropological and forensic dental age estimation results are reported for each analyzed subject.

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Per subject all the forensic dental age estimates were compared with the anthropological age estimates. A high variability in forensic dental age estimates was noted with the majority of them falling out of the anthropological age ranges (Figure 2). Only in six out of 24 subjects did the majority of dental age estimates fall within the anthropological age range. Furthermore only nine mean forensic dental age estimates fell in the corresponding anthropological age range (Figure 3).

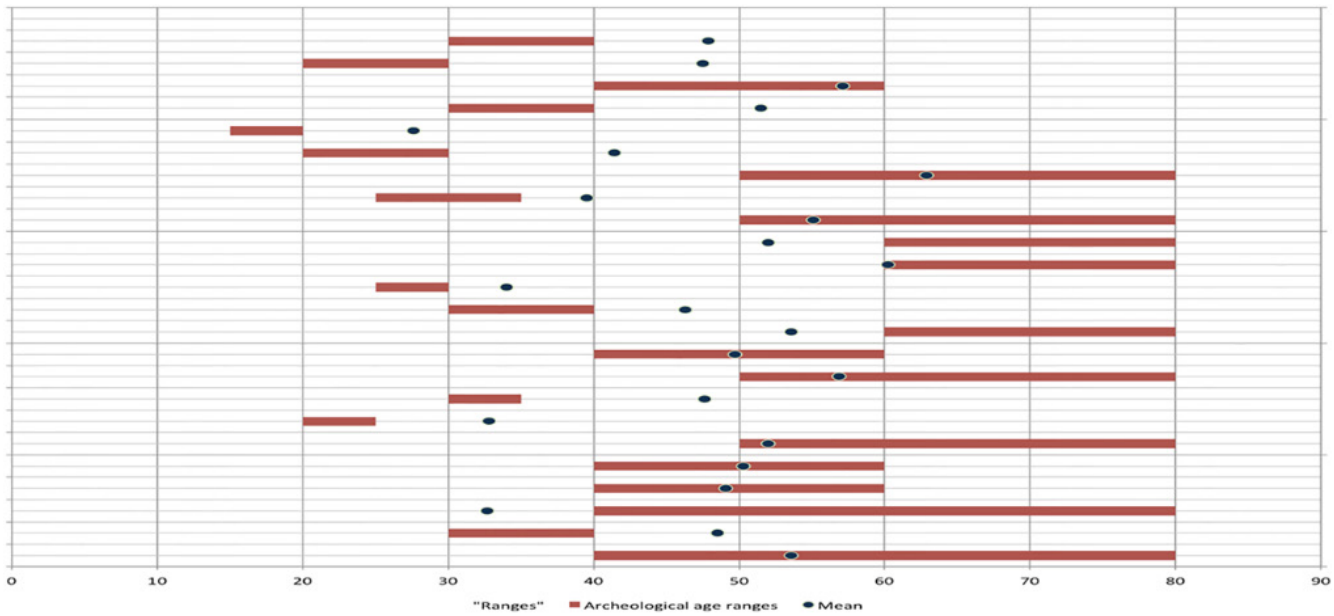

Figure 3: Mean of the point predictions of forensic dental age estimations and anthropological age estimate range per subject. The red bars represent the age-at-death range given by the anthropologist. The black dots represent the obtained point predictions of the forensic dental age estimations (Mean). Both are reported for each analyzed subject.

Grouping the forensic dental age estimates per used method revealed a high variability between them (Figure 2). The destructive methods showed slightly higher agreement with the archeological age estimates than the non-destructive ones. [16,17] rendered the highest agreement with ten forensic dental point estimates falling within an anthropological age n range. Kvaal et al. [21] rendered the lowest agreement with eight correspondences.

Grouping the forensic dental age estimates according to tooth position, the upper central incisors (n=22) showed the highest agreement (50%) with the anthropological results. Similarly, grouping according to tooth type, the incisors (n=56) showed the highest agreement (58%). Among all the applied forensic dental methods, only [20] required the (estimated) sex for tooth 32 and 42. Seven teeth were analyzed using the equations proposed by these authors and in six cases, the obtained point estimates were older than the anthropological age range.

Discussion

When performing age estimations, the gold standard to validate the prediction performances is the real age at death of the analyzed individuals. As is always the case when dealing with archeological collections, this information was lacking and the only existing age estimates eligible to be used as reference were the anthropological age estimates. Moreover, demographic information on Brussels, available in historical sources dating to the 16th century, suggests a lifespan of up to 80 years [26]. The opportunities to work with a well preserved archeological collection and even more, to obtain permission to destroy part of it, are scarce. For these reasons it was decided to carry out the study and to concentrate on the differences in results obtained with forensic methods compared to those from a classical anthropological approach.

To identify factors influencing the age estimation outcomes the obtained age estimates were analyzed in four groups: per used subjects, per age estimation method, per tooth position and per tooth type.

The first group allowed for a direct comparison with the age prediction results obtained by the anthropologist. The observed high variability in the dental point predictions made it impossible to establish a narrower age range than the anthropological one. Although all forensic dental age outcomes provided measures of uncertainty related to each point estimate, performing a meta-analysis was not considered due to the already known high variability in obtained point predictions.

The second group showed a high variability between the mean age estimates per forensic dental age estimation method. This might be explained by the state of preservation of the skeletal remains. An alteration of the macro- and micro-structure due to environmental stress affects mainly the root transparency of the

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tooth [27,28]. This could be the cause of inaccurate measurements in forensic dental age estimation methods based on this parameter [13-18,20]. Moreover, root transparency has been documented to be prone to structural alterations due to taphonomic effects [27,29,30]. For this reason, Vlèek & Mrklas [30] suggested to either exclude or modify root transparency based methods in older samples.

On the other hand, secondary dentin based methods such as [20], avoid the influence of the age-prediction-altering taphonomic effects [27-29]. During the unearthing of the skeletal remains, it was possible to determine that the examined subjects were initially buried in wooden coffins but these disintegrated over time, leaving the skeletons in direct contact with the soil [24]. Undoubtedly the teeth were affected by diagenetic processes, altering their microstructure and, therefore, the reliability of the data registration.

The third group, based on tooth position indicated that forensic dental age estimates from tooth 11 and 21 matched the anthropological results best (50% agreement). The sample size, its heterogeneity in present teeth and the restrictions of teeth allowed to be extracted or cut per subject impeded a fair comparison of results based on tooth position. Moreover, the results were certainly affected by a selection bias of extracted and cut teeth. Indeed, with the knowledge of previously mentioned restrictions and after a literature search, a priority was given to select upper central incisors. This tooth position has been demonstrated to relate best to age for the considered dental parameters [18,19,21].

The fourth group, based on tooth type, indicated that incisors hadthe highest agreement with the anthropological results (58%). However the same reflections as in the third group apply. Therefore, the fact that forensic dental age estimation methods are generally tooth-type- and even tooth-position-specific, limits their application in archeological samples with incomplete dentitions.

The sex was only required on a small number of sampled teeth (n=15). Presumably, this variable did not increase errors in the forensic dental age estimates, since sex estimation methods have proved to be reliable and accurate in the hands of experienced anthropologists, especially when analyzing adults [31].

Finally it is important to note that the forensic dental age estimation methods used the present study were established on contemporary reference samples. Originally Solheim's method was also included in the study, but unrealistic age estimates with no apparent explanation were obtained [19]. This forced its exclusion and suggested to carefully interpret the results of the included methods.

Conclusion

A wide intra-individual variation in age estimates was obtained depending on the forensic dental methods. Moreover the forensic dental and anthropological age estimations differed to a large extent. This was partly explained by the incomplete dentition, the small sample size and diagenetic alterations. Additional analyses on more extensive samples will be needed to verify whether forensic dental and anthropologicall ageing methods can reach higher agreement.

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