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Forensic Anthropology Population Data

Age estimation standards for a Western Australian population using the dental age estimation technique developed by Kvaal et al.

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ABSTRACT

In the present global socio-political scenario, an increasing demand exists for age estimation in living persons, such as refugees and asylum seekers, who seldom have any documentation for proof of identity. Age estimation in the living poses significant challenges because the methods need to be non-invasive, accurate and ethically viable. Methods based on the analysis of the pulp chamber are recommended for age estimation in living adults. There is, however, a paucity of studies of this nature and population specific standards in Western Australia. The aim of the present study is therefore, to test the reliability and applicability of the method developed by Kvaal et al. (1995) for the purpose of developing age estimation standards for an adult Western Australian population.

A total of 279 digital orthopantomograms (143 female; and 136 male) of Australian individuals were analysed. A subset of the total sample (50) was removed as a cross-validation (holdout) sample. Following the method described in Kvaal et al. (1995), length and width measurements of the tooth and pulp chamber were acquired in maxillary central and lateral incisors; second premolars, mandibular lateral incisors; canines and first premolars. Those measurements were then used to calculate a series of ratios (length and width), which were subsequently used to formulate age estimation regression models. The most accurate model based on a single tooth was for the maxillary central incisor (SEE ±9.367 years), followed by the maxillary second premolar (SEE ±9.525 years). Regression models based on the measurement of multiple teeth improved age prediction accuracy (SEE ±7.963 years). The regression models presented here have expected accuracy rates comparable (if not higher than) to established skeletal morphoscopic methods. This method, therefore, offers a statistically quantified methodological approach for forensic age estimation in Western Australian adults.

1. Introduction

In routine casework the accurate estimation of age by a forensic practitioner is a crucial element in the development of a biological profile; this provides vital evidence towards positively establishing the identity of unknown individuals [1]. The requirement for such estimations are not necessarily limited to investigations involving deceased individuals; in recent years there has been a significant increase in the demand for age estimation in living persons, such as refugees and asylum seekers, to determine adult status. These cases typically involve human trafficking and other criminal investigations where individuals misrepresent their actual age in an attempt to avoid prosecution in the adult criminal justice system [2]. Robust age estimation methods are thus required that are non-invasive, accurate, and medically ethical (e.g. minimal radiation exposure), whilst ensuring compliance with other legalities, including confidentiality and consent [3,4].

Non-invasive imaging modalities, including radiographs, computed tomography (CT) and magnetic resonance imaging (MRI), allow the analysis of biological structures (e.g. various skeletal and dental indicators) for the purpose of estimating age in living individuals. In adults, these methods are based on progressive or degenerative skeletal changes (e.g. epiphyseal fusion of the medial clavicle [5], costal cartilage ossification [6], and cranial sutures closure [7]). Age estimation indicators in adults, however, are highly individualistic and their inherent variability leads to lower accuracy rates (SE ±10 years) as compared to estimates made in the sub-adult (juvenile) skeleton (SE ±1–2 years) [8].

Similarly, dental indicators such as attrition [9], aspartic acid racemisation [10,11], and cementum annulations [12] have been extensively studied for the purpose of developing age estimation standards in adult populations. The assessment of dental attrition can be relatively inaccurate because dental wear is influenced by numerous factors, e.g. the types of food consumed and other personal habits, such as tobacco consumption [13]; this method is

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certainly too inaccurate for forensic application. Although affected by environmental factors such as temperature (higher temperature increases rate of racemisation), aspartic acid racemisation in dentine has been demonstrated to be an accurate adult age estimation method (SEE ±1.5–4 years, $r = 0.97–0.99$) [3]. Similarly, methods based on cementum annulation have also yielded promising results (SEE ±4–10 years, $r = 0.78–0.93$) [3]. It is important to note, however, that the latter two methods are invasive (they require sectioning and pulverising of extracted teeth), expensive, and also require specialised equipment and expertise [10–12]; those methods are thus not suitable for application in living individuals.

In further considering the analysis of age-related dental markers, Gustafson [14], following on from the pioneering work of Bodecker [15] demonstrated that secondary dentine deposition and root dentine transparency had the strongest correlation with chronological age. The former relationship was subsequently confirmed by Dalitz ($r = 0.61$) [16], Johansson ($r = 0.66$) [17]; Kvaal et al. ($r^2 = 0.56$ to 0.76) [18], and Drusini et al. ($r = -0.87$ to -0.92) [15]. Kvaal et al. [18] developed a revised method of age estimation, which contrary to their previous method (which required dental extraction [19]) was based solely on radiological measurements; the standard error of estimate ranged from ±8.6 to 11.5 years. As it is a relatively non-invasive approach, the Kvaal et al. [18] method is recommended by the American Society of Forensic Odontology for age estimation in living adults [20].

It is important that age estimation methods are developed for use within a specific population; it is generally accepted that the application of 'foreign' standards results in a loss of prediction accuracy [3,18]. To that end, and in recognition of the general paucity of Australian age estimation standards based on the quantification of secondary dentine deposition, the specific aims of the present study are: (i) to assess the accuracy of the Kvaal et al. [18] method as applied to measurements acquired in digital orthopantomograms (OPGs) in a Western Australian population; and (ii) to develop contemporary adult age estimation standards that have potential forensic application in that population.

2. Materials and methods

2.1. Materials

2.1.1. Sample population

The study sample comprises digital OPGs of 279 Australian adult individuals (143 females and 136 males). The age range for females is 20–73 years (mean 36.73); for males it is 20–62 years (mean 35.26). A subset of the sample (25 female and 25 male) was removed as a holdout (or cross-validation) group. The OPGs were obtained from the Picture Archive and Communication Systems database (PACS), which contains medical scans from various Western Australian hospitals (e.g. Sir Charles Gairdner Hospital, Royal Perth Hospital) and private practices. The OPGs studied were taken during routine therapeutic treatment of individuals presenting for clinical evaluation, and as such there was no unnecessary or repeated radiation exposure. All OPGs were anonymised prior to receipt, so that patient privacy was maintained. The only information retained was the allocated age and sex data. The specific ethnicity of the individuals is unknown, however it is known from Census data that the 'typical' Western Australian population is predominantly Caucasian [21]. Ethics approval to undertake this project was granted by the Human Research Ethics Committee of the University of Western Australia (RA/4/1/4058).

2.1.2. Teeth analysed

The specific teeth analysed include: the maxillary central and lateral incisors, second premolars, mandibular lateral incisors, canines and first premolars. The original method developed by Kvaal et al. [18] only analysed those OPGs in which all six teeth were present and suitable for analysis. In the present study, OPGs with any combination of the required teeth suitable for measurement were analysed. However, the holdout sample only comprised OPGs in which all six teeth were present and suitable for measurement. As Kvaal et al. [18] demonstrated no statistically significant bilateral variation, the present study utilised teeth from either side that fulfilled the defined selection criteria (see below).

2.1.3. Selection criteria

In determining the suitability of the OPGs for inclusion in the present study, any teeth with rotations and large areas of enamel overlap between neighbouring teeth were excluded, as were teeth with restorations, dilarected roots, endodontic treatment, caries, and pathologies (including peri-apical lesions). Secondary dentine is usually formed along the lateral walls of the pulp chamber than on the roof. In multi-rooted teeth it is usually thicker on the pulpal floor, as compared to the lateral walls. Irregular secondary dentine (or tertiary dentine) is formed in response to pathological stimuli such as caries and trauma. Secondary dentine cannot be differentiated from tertiary dentine on radiographs [22–24]. Therefore, in the present study it was vital to include clinically sound teeth. Further, any OPGs demonstrating incorrect patient head alignment (e.g., with the patient's chin and occlusal plane rotated upwards) were also excluded, because this resulted in the overlapping of the opaque shadow of the hard palate, thus obscuring the roots of maxillary teeth. Finally, all of the teeth analysed were required to be in normal functional occlusion.

2.2. Methods

2.2.1. Measurements

The methodological approach of the present study follows Kvaal et al. [18]. As the OPGs were provided in two formats (JPEG and digital) the required tooth measurements were acquired (by SK) using two different software packages, respectively: (i) the ImageJ software (developed by the National Institute of Health, USA); and (ii) the manufacturer provided OPG visualisation software (CDViewer). Measurements definitions accordingly follow those of Kvaal et al. [18] and are defined in Table 1 and Fig. 1. The maximum tooth length, pulp length and root length was measured for each tooth. The radicular portion of each tooth was then divided into three levels (A, B and C) and the root and pulp width was measured at each. The odontometric data was then used to calculate the 'Kvaal dental ratios': the tooth/root length; the pulp/root length; the pulp/tooth length; and the root width/pulp width ratios at the three levels (A, B and C). Age estimation predictors were then calculated based on these ratios (Table 2). The M and (W-L) values were used in the subsequent multiple regression analyses to formulate the regression models.

Table 1
Notation and description of dental measurements (following Kvaal et al. [18]).

Measurement	Notation	Description
Maximum tooth length	T	Distance from the incisal edge or cusp tip to the root apex.
Maximum pulp length	P	Distance from the pulp horn to the root apex.
Maximum root length	R	Distance from the cemento-enamel junction on the mesial aspect to the root apex.
Level A	A	The level of the cemento-enamel junction (CEJ).
Level B	B	Midpoint between levels A and C.
Level C	C	Mid-root level (or midpoint) between the CEJ and root apex.