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Forensic Anthropology Population Data

Skeletal age estimation in a contemporary Western Australian population using the Tanner–Whitehouse method

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ABSTRACT

Various age estimation techniques have been utilised in Australia to evaluate the age of individuals who do not have documentation to determine legal majority/culpability. These age estimation techniques rely on the assessment of skeletal development as visualised in radiographs, CT scans, MRI or ultrasound modalities, and subsequent comparison to reference standards. These standards are not always population specific and are thus known to be less accurate when applied outside of the original reference sample, leading to potential ethical implications. Therefore, the present study aims to: (i) explore the variation in developmental trajectories between the established Tanner–Whitehouse (TW) age estimation standards and a Western Australian population; and (ii) develop specific hand-wrist age estimation standards for the latter population.

The present study examines digital anterior–posterior hand-wrist radiographs of 360 individuals 0 to 24.9 years of age, equally represented by sex. Each radiograph was assessed using the RUS, Carpal and 20-bone methods of Tanner et al. The standard error of the estimate (SEE) was calculated for each method (range: ♀ SEE ±0.4–11.5 years; ♂ SEE ±0.9–10.1 years). The most accurate method was TW3 RUS for females and the TW2 Carpal system for males. The 50th centile skeletal maturity scores for each year age group were plotted against average chronological age to produce polynomial regression standards with a demonstrated accuracy of (♀ SEE ±0.09–3.46 years; ♂ SEE ±0.02–3.42 years) for females and males, respectively. The standards presented here can be used in future forensic investigations that require age estimation of hand-wrist bones in a Western Australian population, however, they are not appropriate for establishing age of majority (18 years), as skeletal maturity was attained on average earlier than 15 years of age in both sexes for all three systems examined.

1. Introduction

With increasing global migration there is a growing requirement for forensic anthropologists to provide age estimates for living individuals who cannot provide documentary evidence of their date of birth, and therefore their chronological age [1]. This has been the subject of considerable debate, due to both the ethical implications of estimating age in living individuals, in addition to criticism of the potential methods available [2–4]. There are several anthropological based techniques for estimating age in living individuals; these techniques largely involve dental analysis [5] and/or the radiographic evaluation of skeletal development in the clavicle [6], elbow [7], knee [8], foot [9] and hand-wrist [10–12]. Outside of dental analysis, the latter are the most widely studied attributes towards making an informed estimation of age [13]. To that end, age estimates in living individuals thus rely on the analysis of radiographs or computed tomographic (CT) scans of localised skeletal morphology in order to evaluate skeletal development based on morphology and/or metrics. The degree of skeletal development relative to full maturity is then used to infer chronological age [14].

Chronological age estimates are most frequently derived from the quantitative statistical analysis of skeletal morphology using population-specific standards; however, such analyses are in actuality only an estimate of 'skeletal age'. The latter, however, does not necessarily accurately represent chronological age, as individual growth, development and senescence varies in relation to a variety of complex inter-related factors, including socioeconomic status, access to adequate nutrition and health care, environment, exposure to pathogens, and genetics [15,16]. Schmeling et al. [17] have

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demonstrated that socioeconomic factors have a major influence on the rate of skeletal development, with individuals of a lower socioeconomic status being generally more prone to poor nutrition, pathology and trauma through lack of adequate medical care. Conversely, in low socioeconomic populations with high mortality rates, skeletal development can be advanced due to an earlier onset of puberty as a result of evolutionary pressure to reproduce [18]. Environmental factors such as dietary intake [19], exposure to certain chemicals and hormones (e.g. phytoestrogens and phthalates) [20], and childhood obesity can also affect growth during puberty, thereby delaying or advancing skeletal development [21]. Irrespective, the assessed skeletal age is often used to infer a chronological age estimate where no other documentation is available [4].

In Australia, there has been considerable controversy surrounding the methods used to estimate the age of individuals charged with people smuggling offences and whom claim to be under the age of legal majority (18 years). An inquiry by the Australian Human Rights Commission in 2012 [22] highlighted perceived deficiencies in practice, whereby there was a reliance on the Greulich and Pyle (1959) hand-wrist atlas approach [23], without due consideration of method reliability or applicability to individuals not representative of the original reference sample. There are alternative hand-wrist skeletal age estimation methods available to the forensic practitioner, such as the widely validated Tanner–Whitehouse methods [11,12], and accordingly it is timely to revisit the biological foundation of such approaches, in addition to evaluating their reliability and accuracy when applied to individuals from populations geographically, genetically and temporally removed from the original study.

The forensic anthropological community in Western Australia is currently working towards developing a suite of population specific anthropological standards based on the analysis of various medical image modalities (e.g. radiographs and CT scans) drawn from a database containing individuals representative of the contemporary Australian population [24,25]. This type of empirical research furthers the knowledge of human variation and helps guide appropriate forensic practice [1]. Thus, the objective of the present study is to statistically quantify the reliability and accuracy of the TW RUS, TW Carpal and TW 20-bone methods in a Western Australian population. The specific aims are: (i) to explore the variation in developmental trajectories between the original reference and the Western Australian population; and (ii) to develop population specific hand-wrist age estimation standards for a Western Australian population.

2. Materials and methods

2.1. Materials

The present study examines digital anterior–posterior hand-wrist radiographs representing 360 individuals equally divided by sex, who presented to various Western Australian (Perth region) hospitals for clinical evaluation of symptoms most frequently relating to hand-wrist bone trauma, or soft tissue injuries, such as strains and sprains. A separate hold-out sample comprising 50 individuals, equally divided by sex, and from the same hospital Picture Archives and Communication System (PACS) database, is used to validate the study results. Scans presenting obvious congenital or acquired hand-wrist pathology (e.g. serious fractures) were excluded if normal morphology and/or the ability to perform a reliable assessment were compromised. The standardised protocol for acquiring the hand-wrist X-rays is as follows: Focus Receptor Distance (FRD): 100 cm; Focus Object Distance (FOD) ~98 cm; Object Receptor Distance (ORD) ~2 cm [24]. Research involving accessing patient data of living individuals in Australia must be in accordance with the National Statement on Ethical Conduct in Human Research (2007 – updated 2014) [26]. As such, all scans were anonymised prior to receipt by the chief investigator (DF), with only sex and age data retained. Accordingly, a successful application for permission to undertake the study was submitted to, and subsequently approved by, the Human Research Ethics Committee of the University of Western Australia (RA/4/1/4362).

For the male individuals in the main sample the age range is 0.01–24.31 years (mean 9.98 years); the corresponding values for the female cohort are 0.02–24.2 years (mean 9.84 years). The sample included a minimum of two individuals per 6 month age group, with an average of five individuals per year age group (e.g. 1–1.99 years of age). The hold-out sample comprised 50 individuals, equally distributed by sex. The male sample had an age range of 3.15–15.67 years; with a corresponding range of 3.01–15.56 years for the female cohort. Chronological age was calculated by subtracting the date of scan from the recorded date of birth. An inherent limitation of most medical imaging modalities is that patient ethnicity is not recorded at any time during clinical evaluation, as such data is deemed not medically relevant. The ethnic composition of the sample, however, is taken as being representative of the Western Australian population as a whole, which according to the latest census data is predominantly European in origin [27].

2.2. Methods

2.2.1. Tanner–Whitehouse methods

The hand-wrist radiographs are analysed (by AM) using the following Tanner–Whitehouse methods: TW2 RUS; TW2 Carpal; TW2 20-bone; and TW3 RUS scoring systems [11,12]. The Tanner Whitehouse methods assign each skeletal region of interest an alphabetic stage of development, from A to either H or I (as shown in Figs. 1 and 2). Stage A (not shown) represents no development, or where the epiphysis (or bone) is not present. Stage I, therefore, represents full skeletal development (fusion completed), although some specific elements (such as the ulna) are only scored up to Stage H (fusion commencing) due to their variable morphology during this period of development. Each alphabetical stage has an associated sex-specific numerical score that is summed to produce a skeletal maturity score; a score of 1000 represents full skeletal maturity (maximum estimable age). Each TW method also has a minimum estimable age (e.g. 2 years old for TW3 RUS) and as such any individual presenting development equivalent to younger than that age limit cannot be assessed using their method (see Table 1 for estimable age ranges).

In order to derive and estimation of skeletal age, the skeletal maturity score is compared to the centile curves and age estimation tables defined by Tanner et al. [11,12]. The skeletal elements assessed are dependent on which scoring method is applied: the RUS method scores the radius, ulna, and the metacarpals and phalanges of the 1st, 3rd and 5th digits (see Fig. 3a); the carpal method scores all of the carpals except the psiform (Fig. 3b); and the 20-bone method scores all of the elements of both the RUS and carpal methods.

2.2.2. Statistical analyses

All statistical analyses outlined below were performed using the *Statistical Package for the Social Sciences (SPSS)*, version 19 and Microsoft Excel 2010.

2.2.2.1. Intra-observer accordance. Intra-observer accordance of hand-wrist assessment is evaluated prior to primary data collection using 20 randomly selected hand-wrists analysed (by AM) on two occasions with a minimum of one week between repeat assessment. The 20 elements used in the 20-bone method were assessed by stage and assigned a sex-specific score, so that