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Forensic Anthropology Population Data

Estimation of sex from the metric assessment of digital hand radiographs in a Western Australian population

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ABSTRACT

The forensic anthropologist is responsible for contributing to the identification of an unknown by constructing a biological profile from their skeletal remains. Towards achieving this goal, anthropologists can apply population and temporally specific standards with known error margins to morphometric data collected from a decedent. Recent research relating to the formulation of sex estimation standards has focussed on the assessment of bones other than the traditionally favoured pelvis and cranium, such as long bones of the appendicular skeleton. In particular, sex estimation standards based on morphometric data from metacarpals and phalanges have reported classification accuracy rates of 80% (and above) based on a narrow range of populations. The purpose of this study is to provide population-specific hand bone sex-estimation standards for a contemporary Western Australian population.

The present study examines digital right hand radiographs of 300 adults of known age, equally represented by sex. A total of 40 measurements were taken in each hand (metacarpals and proximal phalanges); the measurements were then analysed using univariate statistics and cross-validated direct and stepwise discriminant function analysis. All hand bone measurements were significantly sexually dimorphic, with a tendency for the width measurements to express a higher degree of dimorphism than the length measurements. A maximum cross-validated classification accuracy of 91% was achieved with a sex bias of -6%. The standards presented here can be used in future forensic investigations that require sex estimation of hand bones in a Western Australian population.

1. Introduction

The use of forensic anthropology in medico-legal investigations has become more common over time, with an increasing number of cases involving remains that are 'problematic' for a forensic pathologist [1,2]. Such cases are often referred to a forensic anthropologist and include those concerning skeletal, partially fleshed, charred or dismembered remains. Forensic anthropology is the application of concepts derived from the theory and methods of physical anthropology to a forensic investigative context [2,3]. Analysis of human skeletal remains covers any aspect of the biological profile (osteobiography) that aids towards establishing personal identity or manner of death [4,5]. A biological profile includes estimating ancestry, sex, age, and stature through metric and non-metric analyses of skeletal remains; this data can thus be used to narrow the pool of possible matching identities.

Biological sex is a primary component of the osteobiography and is generally one of the first to be assessed; standards for subsequent estimations (age and stature) are largely sex-specific [1,6]. Sexual dimorphism is the biological foundation of sex estimation and is defined as the physical and behavioural differences that occur between males and females [7,8]. Sex differences in the shape, size and appearance of bones arise during development according to individual genetic markers and in response to sex hormones during puberty; bone development being dependent on a combination of genetic markers and hormone exposure [8]. The age at which these sex-specific morphological changes occur is subject to a number of population specific genetic and environmental factors [8]. As the degree of sexual dimorphism, and the age at which it occurs in males and females, varies between populations (who may differ geographically, temporally or by ancestry) sex estimation standards are

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required to be population specific [9,10]. Standards used to analyse morphometric data are thus most accurate when applied to the population from which they are derived [10,11].

Although the pelvis is highly sexually dimorphic, and therefore the preferred element for sex estimation, recent research has worked towards quantifying the sex estimation potential of other skeletal elements [12]. Previous research has demonstrated that the sternum [9], femur [13], metatarsals [14] and metacarpals [15] can be used to correctly classify sex with a high degree of expected accuracy (above 80%). However, and with specific reference to the hand bones, Burrows et al. [11] demonstrated that the application of skeletal standards for metacarpals formulated for one population can be less accurate when applied to another that is geographically removed; this can be attributed to population and temporal differences between the samples specific to each study. When standards are applied inappropriately, the errors highlighted by Burrows et al. [11] have a potentially significant impact on the value of anthropological evidence in legal proceedings. It is therefore crucial that population-specific standards are applied.

The Western Australian (WA) population is deemed to be more ethnically diverse than other states and territories of Australia, with Perth being one of the most diverse capital cities [16]. The Western Australian population comprises 3.1% indigenous Australians, which is higher than the Australian average (2.5%), but considerably lower than the Northern Territory (26.8%) (Table 1) [17]. Australian Bureau of Statistics [18] data indicate that 56.2% of the WA population have one or more parent born overseas and 75% have an ancestry other than Australian (within two generations). This compares with Australia as a whole where 46.2% of people have one or more parent born overseas. In broad terms the population is predominantly Caucasian in all Australian states (but not territories) [19]. As no Australia-wide anthropological studies have been undertaken, we treat the WA population as distinct, albeit it is anticipated that the standards produced here are more applicable to other Australian states than they would be to other non-Australian populations.

The aim of the present study is to formulate sex-estimation standards based on metacarpal and phalange measurements of digital hand radiographs, applicable to a Western Australian population. This study forms part of an ongoing project dedicated to the development of population specific anthropological standards for Australian forensic practitioners.

2. Materials and methods

2.1. Materials

The sample comprises 300 posterior–anterior (PA) digital radiographs acquired from the Western Australian Department of Health (WA DoH) Picture Archiving and Communication Systems (PACS) database. The right hand of 150 adult males and 150 adult females are examined; the stated age range for males is 18.3–64.3 years (mean 41.9) and 18.5–68.4 years (mean 42.8) for females. The medical images are acquired from various Western Australian hospitals and relate to patient admissions for clinical evaluation of the hand-wrist (generally sprains and other soft tissue injuries) between 2011 and 2013. 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 – resultant magnification is standardised at ≤2% (generally less than variation introduced by intra-observer measurement precision – see below). Only radiographs that show little (or compete absence of) skeletal trauma and/or anomalies in the metacarpals and proximal phalanges are included. In accordance with standard research ethics requirements and the inherent constraints of using medical data, the radiographs are received anonymised, with only age and sex information for each individual retained. In this study, ancestry of the subjects is not known (nor is ethnicity recorded at hospital admission as it is not deemed to be of medical relevance), however ancestry is generally taken to approximate a representative sample of the contemporary Western Australian population (see above).

2.2. Methods

2.2.1. Measurements from digital radiographs

The 40 linear measurements used in this study follow previously published definitions [15,20] adapted for 2D images; four measurements are acquired for each metacarpal (MC) and proximal phalanx (PP) (Table 2 and Fig. 1). The OsiriX® line-tool function is used to define the linear measurements (in millimetres).

2.2.2. Statistical analyses

A 6 × 6 precision study was performed to statistically quantify the degree of intra-observer error and therefore determine the quality of the subsequent data collected. Six randomly selected hand radiographs were measured a total of six times each, with a minimum of one day between repeats to minimise data recall. The error associated with measurement repeats was calculated using the *technical error of measurement* (TEM), *relative TEM* (rTEM), and *coefficient of reliability* (*R*) statistics (see [21–24] for detailed explanations of these approaches).

Descriptive statistics (mean, standard deviation and range) were calculated and assessed for outliers prior to subjecting the data to further statistical analyses. The mean hand bone measurements of males and females were compared using one-way ANOVA with sex as the dependent variable and individual hand bone measurements as the independent variables.

Table 1
Australian Bureau of Statistics, 2011 Census data: Ancestry (primary response) by state.

	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	OT[a]	Aust. Average
Australian Aboriginal	2.5%	0.7%	3.6%	1.9%	3.1%	4.0%	26.8%	1.4%	29.0%	2.5%
Non-indigenous Australian	20.5%	20.5%	23.2%	21.3%	19.2%	30.0%	17.7%	24.2%	13.2%	22.7%
North-West European	41.4%	42.0%	51.3%	50.6%	49.1%	49.7%	13.8%	45.1%	8.0%	45.3%
Southern and Eastern European	8.4%	12.7%	4.1%	9.9%	7.1%	2.3%	3.6%	7.4%	0.9%	8.4%
North African and Middle Eastern	3.8%	2.5%	0.5%	0.8%	0.9%	0.3%	0.3%	1.1%	0.2%	2.1%
South-East Asian	3.0%	3.0%	1.5%	2.0%	2.5%	0.5%	3.2%	2.8%	14.5%	2.5%
North-East Asian	6.1%	4.8%	2.5%	2.5%	3.5%	1.1%	2.1%	4.5%	13.7%	4.3%
Southern and Central Asian	3.6%	4.1%	1.5%	2.1%	2.4%	0.6%	1.7%	4.0%	0.8%	3.0%
Peoples of the Americas	0.8%	0.5%	0.5%	0.4%	0.5%	0.3%	0.4%	0.8%	0.1%	0.6%
Sub-Saharan African	0.5%	0.8%	0.6%	0.5%	1.5%	0.3%	0.6%	0.6%	0.3%	0.7%
Other	2.7%	1.9%	3.4%	2.4%	2.6%	5.0%	18.2%	2.8%	16.2%	1.1%
Not stated	6.9%	6.5%	7.3%	5.7%	7.6%	5.9%	11.6%	5.4%	3.2%	6.9%

[a] Other Territories: Christmas Island, the Cocos (Keeling) Islands, and the Jervis Bay Territory.