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Forensic Anthropology Population Data

Age prediction formulae from radiographic assessment of skeletal maturation at the knee in an Irish population

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ABSTRACT

Age estimation in living subjects is primarily achieved through assessment of a hand–wrist radiograph and comparison with a standard reference atlas. Recently, maturation of other regions of the skeleton has also been assessed in an attempt to refine the age estimates. The current study presents a method to predict bone age directly from the knee in a modern Irish sample. Ten maturity indicators (A–J) at the knee were examined from radiographs of 221 subjects (137 males; 84 females). Each indicator was assigned a maturity score. Scores for indicators A–G, H–J and A–J, respectively, were totalled to provide a cumulative maturity score for change in morphology of the epiphyses (AG), epiphyseal union (HJ) and the combination of both (AJ). Linear regression equations to predict age from the maturity scores (AG, HJ, AJ) were constructed for males and females. For males, equation-AJ demonstrated the greatest predictive capability ($R^2 = 0.775$) while for females equation-HJ had the strongest capacity for prediction ($R^2 = 0.815$). When equation-AJ for males and equation-HJ for females were applied to the current sample, the predicted age of 90% of subjects was within ±1.5 years of actual age for male subjects and within +2.0 to −1.9 years of actual age for female subjects. The regression formulae and associated charts represent the most contemporary method of age prediction currently available for an Irish population, and provide a further technique which can contribute to a multifactorial approach to age estimation in non-adults.

1. Introduction

Assessment of age in living subjects has come to the fore in recent years especially with increasing levels of migration between different countries [1–5]. Verification of age is required mainly for legal reasons, but is often also required in clinical situations. In the absence of valid identification documentation estimation of biological age involves radiographic assessment of dental and skeletal maturity. Dental development extends from the intra-uterine period until the early 20s making it particularly useful for age estimation [6,7]. Where dental records are incomplete estimation of biological age commonly involves assessment of radiographs of the hand–wrist and comparison to an age based reference standard such as the atlas of Greulich and Pyle [8], developed on a 1930s white population from Cleveland, OH, U.S. [1,2]. The utility of this method extends to the 17th year in females and the 19th year in males, when maturity of the hand–wrist is achieved. After this time-frame assessment of the medial epiphysis of the clavicle, is most useful for estimation of age for forensic purposes [9–11]. Application of relevant standards is critical to ensure appropriate estimates of age are obtained, as standards routinely used for a jurisdiction may be invalid for use for subjects who have migrated to an alternate jurisdiction.

Skeletal maturation is known to vary across different population groups. It has been reported that black children are more advanced in their skeletal development than their white counterparts and that Asian and Hispanic subjects mature in advance of both black and white subjects for both males and females [12–18]. It is therefore necessary to collect data on skeletal maturation for subjects from different population groups. Application of inappropriate standards can potentially result in an inaccurate estimate of age which may be of major significance to some legal cases but could also impact clinical judgement and decision making.

Contemporary information on skeletal development is also required, as secular variation may also impact on the validity of anthropological techniques when applied to modern population groups. As stature has increased and the age of sexual maturation has decreased through the nineteenth and twentieth century,

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skeletal maturation has also likely been impacted [19–25]. It is therefore necessary to obtain current data for populations, to ensure accurate estimation of age in clinical and forensic scenarios but also to provide a baseline from which to assess any further secular variation. Radiography allows examination of living subjects and the construction of more representative contemporary standards for age estimation.

This paper presents formulae for age prediction from radiographic assessment of skeletal maturation at the knee in a contemporary Irish population sample.

2. Materials and methods

2.1. Sample

Radiographs from 221 subjects (137 males; 84 females) aged 9–19 years who presented for an X-ray of the knee through the Accident and Emergency or Out-patient Departments at Cork University Hospital (CUH), Ireland, during 2002 were retrospectively included in this study. All subjects included were resident in Ireland. No subject with a previous knee X-ray or prior surgery to the knee; diagnosed bony trauma or pathology of the knee following assessment of the radiograph; or history of an underlying endocrine, metabolic or nutritional disorder was included in the study. The chronological age of each subject was calculated using information provided on the date of birth and the date of registration for X-ray, therefore allowing calculation of exact age (y) at the time of X-ray. Each individual had an antero-posterior and a lateral radiograph of the knee available for assessment.

2.2. Assessment of skeletal maturity

Ten indicators of skeletal maturity were examined from the radiographs of each subject (Table 1, Fig. 1). Indicators which observed the change in morphology of the epiphyses (indicators A–G) and epiphyseal union at the knee (indicators H–J) were assessed using the criteria outlined by O'Connor et al. [26,27]. This involved examination of an antero-posterior and lateral knee radiograph using the written criteria and representative images for each of the grades of development of the maturity indicators (A–G) and stages of epiphyseal union (H–J). A stage of development was assigned for each indicator such that each individual had a grade of development recorded for each of the ten indicators A–J. The numerical value associated with the grade of development was taken as the maturity score for a given indicator. For example, if indicator-A was absent, a score of 0 was recorded, if it was present, a score of 1 was recorded and so forth for each indicator (Table 1). Scores for indicators A–G, H–J and A–J, respectively, were totalled to provide a summative maturity score based on change in morphology of the epiphyses

Table 1
Summary of maturity indicators assessed as per O'Connor et al. [26,27].

Indicator	Description	Grade/stage	Description[b]
A	Proximal projection of the lateral corner of the distal femoral epiphysis	0	Projection absent
		1	Projection present
		2	Fused
B	Lateral capping[a] of the metaphysis by the distal femoral epiphysis	0	Capping absent
		1	Capping incomplete
		2	Capping complete
		3	Fused
C	Development of the tubercles of the intercondylar region of the tibia	0	Developing
		1	Present
D	Distal projection of the lateral corner of the proximal tibial epiphysis	0	Projection absent
		1	Projection present
		2	Fused
E	Distal projection of the medial corner of the proximal tibial epiphysis	0	Projection absent
		1	Projection present
		2	Fused
F	Development of the tibial tuberosity	0	Absent
		1	Developing
		2	Fusion incomplete distally
		3	Fusion complete
G	Development of the styloid process of the fibula	0	Absent
		1	Early development
		2	Present
H–J	Epiphyseal union of the femur, tibia and fibula	0	Non-union: Continuous radiolucent gap between epiphysis and diaphysis
		1	Beginning union: >50% of the growth plate is radiolucent
		2	Active union: <50% of the growth plate is radiolucent
		3	Recent union: Epiphysis and diaphysis are united as a single unit of bone, but there is discontinuity of trabeculae between epiphysis and diaphysis and notches at the peripheral margins of the bone (<2 mm)
		4	Complete union: Epiphysis and diaphysis are united as a single unit of bone with continuity of trabeculae and absence of radiolucent notches at the peripheral margins of the bone

[a] Capping refers to the way in which the epiphysis overlaps the metaphysis as maturation proceeds.
[b] Assessment criteria for maturity indicators as per descriptions outlined by O'Connor et al. [26,27].