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Age estimation based on bone length using 12 regression models of left hand X-ray images for Asian children below 19 years old

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ABSTRACT

Age estimation was used in forensic anthropology to help in the identification of individual remains and living person. However, the estimation methods tend to be unique and applicable only to a certain population. This paper analyzed age estimation using twelve regression models carried out on X-ray images of the left hand taken from an Asian data set for subjects under the age of 19. All the nineteen bones of the left hand were measured using free image software and the statistical analysis were performed using SPSS. There are two methods to determine age in this study which are single bone method and all bones method. For single bone method, *S*-curve regression model was found to have the highest *R*-square value using second metacarpal for males, and third proximal phalanx for females. For age estimation using single bone, fifth metacarpal from males and fifth proximal phalanx from females can be used due to the lowest mean square error (MSE) value. To conclude, multiple linear regressions is the best techniques for age estimation in cases where all bones are available, but if not, *S*-curve regression can be used using single bone method.

1. Introduction

Forensic anthropology is the application of methods and knowledge of physical anthropology to solve medical problems with legal significance. The objective is usually to help in the identification of individual to predict what has happened, especially with regards to the evidence of foul play [1]. There have been some attempts to identify individuals using hand measurements [2], vertebral column length [3], leg length [4] and step length [5] in living persons. In addition, there have been several studies conducted on stature estimation from foot length [6] and cephalo-facial dimensions [7] in school age children.

Age estimation in living individuals often presents a clinical forensic medicine challenge with significant social and important legal concerns. Forensic identification requires increasingly sensitive and specific age estimation methods. For children, age estimation can be performed very accurately using morphological methods, because a great number of age-dependent morphological features (especially of the dental and skeletal system) can be evaluated. At the end of skeletal growth and development, only a few age-dependent features (e.g. the development of the third molars and bones of the wrist and hand) remain to be used for age estimation by morphological methods, resulting in a gradual decrease in accuracy with the increase of age. During adulthood, the accuracy of most morphological methods is poor; in this age group, a biochemical method (based on aspartic acid racemization in dentin) offers the most accurate results. Age estimation can be used if the identity of a victim of a murder case is unclear or if legal questions concerning children's imputativeness have to be clarified. In such cases, age estimation in childhood may play a central role in the clarification of questions which has a major legal and/or social impact on the individual as well as on the community; this is the peculiarity of age estimation in forensic practice [8].

Various human anatomical sites have been analyzed in the estimation of age including the knee [9], teeth [10,11], and hand-wrist bones [11–13]. For the latter, several methods have been used such as Greulich and Pyle [12–14], linear regression [9,14], multiple regression [10], single quadratic regression (SQR) [11] and support vector regression (SVR) [11].

Literature shows that there are several inherent limitations in the estimation of age affected by different criteria, such as gender, ethnicity, socio-economic citation, nutrition and geographical location [15]. It has been concluded that results obtained from one population are not necessarily applicable in others. As such, specific studies have to be performed as the results would be unique to a particular population. All the reported methods of determining age are also unique to a particular study and may not be applicable

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for different available samples or data sets. Several studies also proved that, after the age of 30, age estimation methods are unreliable, with an average error of 12 years [16,17].

The present study was undertaken to determine age using Asian left hand data sets between the age of newborn and 18 years old. From our literature review, our study is the first study using left hand bone measurement from X-ray images to estimate age by looking at the relationship between bone length and age. In contrast to the techniques used in previous works, 12 regression models, applied to the length of each bone in the left hand and its particular age, namely; Linear, Logarithmic, Inverse, Quadratic, Cubic, Compound, Power, *S*-Curve, Growth, Exponential and Logistic were used for the single bone method, and multiple linear regressions were used for the all bones method.

2. Materials and methods

A total of 333 X-ray images of Asian left hand bones from 166 males and 167 females were included in this study. To overcome ethical issues, these radiographs were collected from Children's Hospital Los Angeles, along with patients' demographic data and radiologists' readings distributed in nineteen groups (newborn, 1–18) for both male and female. Age distribution of the subjects is shown in Table 1. The radiographs were collected by Image Processing and Informatics Lab of the University of Southern California funded by National Institute of Health and restricted for open research and education only. Candidates for this study underwent a protocol approved by the institutional review board for clinical investigations. Each radiograph was digitized to a 2 K × 2 K image using a laser film scanner (Array, Tokyo, Japan); and the patient's demographic records were manually entered via the scanner GUI (graphical user interface) and saved as a DICOM file [18]. The radiographs can be obtained from this website [19]. The age and gender of all radiographs were perfectly documented as a reference. This study has also been approved by the Ministry of Higher Education, Malaysia and ethics committee of our Research Management Centre, Universiti Teknologi Malaysia.

The hand bones can be divided into four groups, namely the distal phalanx, middle phalanx, proximal phalanx and metacarpal. The middle phalanx group consists of four bones while the other three groups have five bones respectively, with the total number of bones for the hand being 19. The data set ranged from newborns to 18-year-olds with no records of bone problems or bone diseases such as fractures, bone cancers, osteoarthritis, rheumatoid arthritis or other genetic bone problems. Bones with these complications should not be included as they are expected to be weakened, bristled, deformed and easy to break, which may affect the measurements.

There are 2 main portions of long bone which are epiphyses and diaphysis in childhood. Epiphyses is the end of a long bone that is originally separated from the main bone by a layer of cartilage but later becomes united to the main bone through ossification when entering adulthood. Diaphysis is the central shaft of a long bone consisting mainly of compact bones surrounding a cavity. These two portions are shown in Fig. 1. During childhood and adolescence, the bone development of left hand can be divided into six major phases which are; (1) Infancy (newborn to 14 months for males, newborn to 10 months for female), (2) Toddlers (14 months to 3 years of age for males, 10 months to 2 years of age for females), (3) Pre-puberty (3–9 years of age for males, 2–7 years of age for females), (4) Early and Mid-puberty (9–14 years of age for males, 7–13 years of age for females), (5) Late Puberty (14–16 years of age for males, 13–15 years of age for females) and, (6) Post-puberty (16–19 years of age for males, 15–17 years of age for females) [32].

Table 1
Age distribution of the subjects divided into six groups of age.

Group of age	Newborn–3	4–6	7–9	10–12	13–15	16–18	Total
Male	17	20	18	44	37	30	166
Female	16	19	23	41	38	30	167

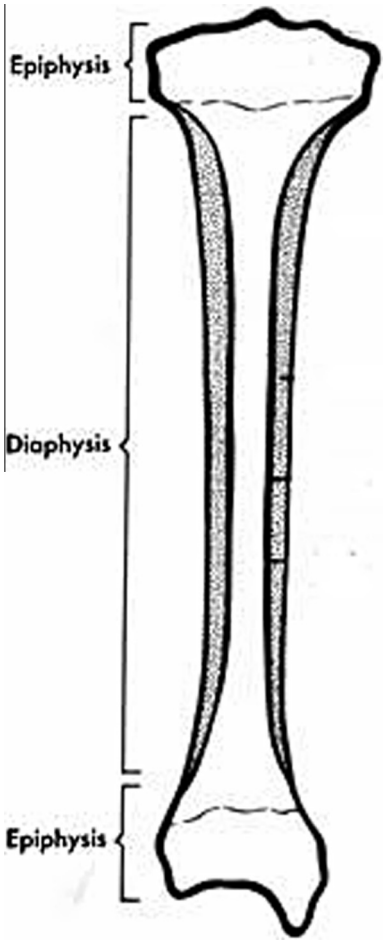

Fig. 1. Two main portions of the hand bone.

To measure each bone length in these phases, a free photo editor (Photo Pos Pro, Power of Software Company Ltd) was used. This software was used to measure all the nineteen bones by creating a line in each bone starting from the base-middle point of bone to the end-middle point of bone on each X-ray images and automatically produced length of the line in centimeter (cm). For infancy phase, the line was created by ignoring the epiphyseal (if occur) in the bone. For other phases, the line is created by including the epiphyseal even if just a small epiphyseal appeared in the images. Fig. 2 shows an example of measuring the bone length of each phase for a male subject from its X-ray image using the software. All the measured data from all images are tabulated in a spreadsheet for analysis.

In order to show the measured data are reproducible and that there was no significant statistical difference between these measurements, an analysis of variance of intra-observer and inter-observer for repeated measures was conducted. For the intra-observer trial, each measurement on each bone in every image was repeated thrice, and the mean of these three measurements were used to design the regression models. Two different observers were used for inter-observer trial. 50 X-ray images were randomly selected and each image was measured by these observers 10 times. Then, another analysis of variance for repeated