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A new formula for assessing skeletal age in growing infants and children by measuring carpals and epiphyses of radio and ulna

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ABSTRACT

The aim of this study is to develop a specific formula for the purpose of assessing skeletal age in a sample of Italian growing infants and children by measuring carpals and epiphyses of radio and ulna. A sample of 332 X-rays of left hand-wrist bones (130 boys and 202 girls), aged between 1 and 16 years, was analyzed retrospectively. Analysis of covariance (ANCOVA) was applied to study how sex affects the growth of the ratio Bo/Ca in the boys and girls groups. The regression model, describing age as a linear function of sex and the Bo/Ca ratio for the new Italian sample, yielded the following formula: Age = −1.7702 + 1.0088 g + 14.8166 (Bo/Ca). This model explained 83.5% of total variance ($R^2 = 0.835$). The median of the absolute values of residuals (observed age minus predicted age) was −0.38, with a quartile deviation of 2.01 and a standard error of estimate of 1.54. A second sample test of 204 Italian children (108 girls and 96 boys), aged between 1 and 16 years, was used to evaluate the accuracy of the specific regression model. A sample paired t-test was used to analyze the mean differences between the skeletal and chronological age. The mean error for girls is 0.00 and the estimated age is slightly underestimated in boys with a mean error of −0.30 years. The standard deviations are 0.70 years for girls and 0.78 years for boys. The obtained results indicate that there is a high relationship between estimated and chronological ages.

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1. Introduction

The increased requirement for age estimation in the living has led to an associated increase in research into age estimation practices and their effect on those who are caught up in the whole process.[1,2] Hand–wrist radiological and dental examinations are the most common methods of age analysis in orthodontics, pediatric dentistry and forensic medicine.[2,3] Both the AGFAD (Study Group on Forensic Age Diagnostics) and FASE (Forensic Anthropology Society of Europe), a subsection of the IALM (International Academy of Legal Medicine), recommends the simultaneous use of physical examination, radiographic examination of the left hand, dental examination, and orthopantomography.[2–4] In addition, to answer the question of whether a person is 18 years old or not, it is particularly helpful to evaluate the ossification status of the medial epiphysis of the clavicle, because all other examined developmental systems may already have completed their growth by that age. The latest version of these recommendations can be found on the AGFAD website at http://campus.uni-muenster.de/6757.html?&L=1.

Concerning the evaluation of the hand-wrist ossification, it is usually accomplished by examining in a conventional radiograph the degree of maturity of the hand-wrist bones.[4,5] In fact, their anatomical structure and disposition in the radiograph allow the observer to analyze the different bones in a way which does not happen in any other part of the skeleton.[6] The hand radiographs are quite safe to obtain as the effective dose of radiation received

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during each exposure is between 0.0001 and 0.1 mSV.[7] This dose is less than 20 min of natural background radiation or the amount of radiation received by an individual on a 2 min transatlantic flight.[7]

Two approaches based on the X-rays image of the left hand-wrist are regularly applied in criminal age estimation practice: the atlas technique in which bone age is assessed by comparing a subject's X-ray with standard radiographs classified by age and sex,[8] and bone-specific scoring techniques which separately determines the maturity of selected skeletal features.[9–12] In some German-speaking countries, the Thiemann-Nitz atlas method is also used.[13] Cameriere et al.[1] developed also a quantitative method based on the ratio between the carpal area and the total area of carpal bones and epiphyses of the radius and ulna.

The aim of this study is to develop a new specific formula, using a regression model, for the purpose of assessing skeletal age in a sample of Italian growing infants and children by measuring carpals and epiphyses of radio and ulna.

2. Material and methods

2.1. Sample

A sample of 332 X-rays of left hand-wrist bones belonging to Italian infants and children (130 boys and 202 girls), aged between 1 and 16 years, was analyzed retrospectively. These images have been generated at the Department of Radiology, University of Rome (Italy), in order to assess the bone maturation of children for orthodontic and auxological purposes. The X-ray images of the hand-wrist bones were created in the period from 2012 to 2015. All the subjects were from the middle socioeconomic class.

X-rays of the left hand were taken in the postero-anterior projection, with fingers slightly splayed. The radiographic images were carried out by Samsung® XGEO GC80 Digital X-Ray System. Exposure doses were calculated by analyzing the peak skin dose and effective dose according to age, zone of exposure and tissue thickness. Instead of adjusting kilovoltage peak (kVp) and milli-ampere-seconds (mAs) around a constant detector exposure, in this study the concept of lowering kVp and increasing mAs to achieve a constant patient dose has been observed, but with an increase in contrast-to-noise ratio (CNR). The amount of kVp varied between 40/4 mAs and 45 kVp/4 mAs. The source image distance (SID) (110 cm) was constant.

The analysis included hand-wrist radiographs of Italian children and adolescents whose physical development was normal. If any indications of a disease which might influence skeletal maturation emerged, this led to exclusion from the study. For this purpose, medical records were obtained for all individuals, in order to exclude children with abnormal stature, overweight or a history of serious disease or chronic illness. In fact, a basic prerequisite for radiographic age estimation is a physical examination in order to establish whether the person has a disease that may affect skeletal development. To infer the chronological age from the skeletal age is permissible only if there is no indication of developmental disorders.[14]

Personal details were also limited to sex, date of birth, date of image, and side of the body. The chronological age for each case was calculated from the date of birth to the date of the X-rays, and was also recorded in a Microsoft Excel® file. The age spread of the radiographs according to sex is given in Table 1.

A second sample of 204 X-rays (108 girls and 96 boys), aged between 1 and 16 years, was used to evaluate the accuracy of the new age estimation formula. The same selection criteria were applied (Table 2). All the children were Italian and belong to the middle socioeconomic class.

Protocols to collect radiographs for human subjects were approved by the Ethics Committee for Research Involving Human Subjects of the University of Rome (Italy), and the study was conducted in accordance with the ethical standards laid down by the Declaration of Helsinki (Finland).

Table 1
Age and sex distribution of the Italian sample.

		Sex		Total
		Girls	Boys	
Age groups	1.1–2.0	6	4	10
	2.1–3.0	8	3	11
	3.1–4.0	15	6	21
	4.1–5.0	19	14	33
	5.1–6.0	9	6	15
	6.1–7.0	15	16	31
	7.1–8.0	23	11	34
	8.1–9.0	25	13	38
	9.1–10.0	31	6	37
	10.1–11.0	15	10	25
	11.1–12.0	11	10	21
	12.1–13.0	6	11	17
	13.1–14.0	6	8	14
	14.1–15.0	7	7	14
	15.1–16.0	6	5	11
Total		202	130	332

2.2. Measurements

Each X-ray image was processed by computer-aided drafting (Adobe® Photoshop® CS5). Following Cameriere et al.,[1] the mathematical area of the carpal bones (Ca) and epiphyses of ulna and radius were identified by manual segmentation and defined by the polygonal lasso instrument of Adobe® Photoshop® CS5. The pixels of these areas were computed and presented in a histogram. The mathematical area of each carpal bone was selected by the polygonal lasso tool, and the pixel areas were calculated and added together to yield the overall values of bone areas (Bo) (Fig. 1). When two bones overlapped, the common area was calculated only once. Lastly, in order to normalize the measurements, the ratio between total area of bones and carpal area (Bo/Ca) was calculated and used for linear regression analysis.

2.3. Intra- and inter-observer agreement

As the possibility of replicating measurements reliably is an indispensable component of any metric study, intra- and inter-observer error was tested.[15] To deal with the random

Table 2
Sex and age distribution of the new Italian sample.

		Sex		Total
		Girls	Boys	
Age groups	1.1–2.0	4	4	8
	2.1–3.0	6	6	12
	3.1–4.0	7	7	14
	4.1–5.0	8	5	13
	5.1–6.0	10	7	17
	6.1–7.0	8	12	20
	7.1–8.0	13	9	22
	8.1–9.0	8	9	17
	9.1–10.0	13	8	21
	10.1–11.0	14	8	22
	11.1–12.0	4	4	8
	12.1–13.0	6	4	10
	13.1–14.0	2	4	6
	14.1–15.0	2	5	7
	15.1–16.0	3	4	7
Total		108	96	204

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