Digital radiographic evaluation of hand-wrist bone maturation and prediction of age in South Indian adolescents

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Abstract

Background In the growing years, indicators of the level of maturational development of the individual provide the best means for evaluating biologic age and the associated timing of skeletal growth. The relative stage of maturity of a child may be determined by comparing the child's hand-wrist radiograph to the known standards of skeletal development.

Aims and Objectives In this study, we assessed various levels of skeletal maturation and also identified the relationship between chronological age (CA) and maturation stage using the hand-wrist radiographs in adolescents of Indian origin.

Materials and Methods Three hundred and thirty hand-wrist digital radiographs of individuals aged 8 to 18 years were evaluated for skeletal maturity levels using Fishman's method. The data was analysed using the SPSS software package

(version 12, SPSS Inc., Chicago, IL, USA). Regression analysis was performed for calculating bone age of both males and females. Spearman's rank-order correlation coefficients were estimated separately for males and females to assess the relation between CA and maturation level.

Results An association between skeletal maturation indicator stages and CA ($r=0.82$) was significant. Interestingly, female subjects were observed to be advanced in skeletal maturity compared to males. Regression equations were derived to calculate bone age in males, females and the whole sample.

Conclusion The results of this study showed significant association between hand-wrist skeletal maturation levels and CA. Digital radiographic assessment of hand-wrist skeletal maturation can be used as a better choice for predicting average bone age of an individual because of its simplicity, reliability and lesser radiation exposure.

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Introduction

Dentofacial orthopaedics has its activity largely concentrated on the interpretation of factors related to individuals' facial growth and development. The evaluation of these factors from the clinical point of view is fundamental for diagnosis and correct treatment planning. It is, therefore, of great value to estimate the patient's biological age, since chronological age is not a reliable parameter in evaluating the skeletal maturation stage. In living persons, the age estimation is done to assess whether the child has attained the age of criminal responsibility in cases such as employment, marriage, premature births, adoption, illegal immigration, paediatric endocrinopathy, orthodontic malocclusion and for legal proceedings [27].

Human beings show considerable variations during growth, at particular ages in which each individual reaches similar developmental events, which has led to the concept of assessing biological or physiological maturity. They include sexual maturation characteristics, facial growth and peak growth velocities, chronological age, dental development, body height, body weight and hand-wrist maturity [9–12, 15, 19]. The principle of skeletal maturation and its estimate dates back to 1908 when Crampton [8] first described it and later developed by Todd [34] and Greulich and Pyle [17] with the use of hand-wrist radiographs.

Adolescence is a period during which the rate of growth acceleration reaches a peak velocity and then decelerates until adulthood is achieved. This pattern can be found in all individuals, but there are marked individual variations in the initiation, duration, rates and amount of growth during this period of life [3].

An accurate assessment of chronological age is provided by developmental stages such as skeletal maturation, secondary sexual characters and dental development. Skeletal maturation refers to the degree of development of bone ossification [27]. Skeletal maturity is a measure of development, incorporating the size, shape and degree of bone mineralization to define its proximity to full maturity. During growth, every bone goes through a series of changes that can be seen radiologically. The sequence of changes is relatively consistent for a given bone in every person. The timing of the changes varies because each person has his or her own biological clock [19]. Skeletal maturation has been shown to occur in identical and defined stages between ethnic groups. However, the differences in the timing of skeletal maturation between ethnic groups might be due to factors like genetic differences, environmental conditions and regional and climatic variations [32]. The skeletal maturation assessed on hand-wrist radiographs is classically considered as the best indicator of maturity and has been found to be closely related to the growth spurt [6, 7, 20]. Skeletal age or bone age is the most common measurement for biological maturation of the growing human and can be derived from the examination of successive stages of skeletal development, as viewed in hand-wrist radiographs. The technique for assessing skeletal age consists of visual inspection of bones, their initial appearance and their subsequent ossification changes in shape and size. Twenty-nine various areas of the skeleton have been used: the foot, the ankle, the hip, the elbow, the hand-wrist and the cervical vertebrae [19]. The hand-wrist radiograph is commonly used for skeletal developmental assessment.

The work of Rotch, Flory, Todd and Greulich and Pyle suggests that hand-wrist region offers a fair index of the maturity of the entire skeleton of the healthy child. The most popular method of assessing maturity has been to base the comparison on a series of films which are typical of the various age groups. Such pictorial standards have been

published by Wilms, Rotch, Englebach and McMahon, Siebert, Flory, Todd, Vogt and Vickers, Greulich and Pyle and Mackay. However, this ‘inspectional’ method involves considerable subjective error. To eliminate the latter, efforts were made to assess maturity by measuring the size of the shadows of various bones on the radiograph. Such techniques were little used outside the centres in which they were devised because they were slow, cumbersome and inaccurate. A third method has been evolved which entails radiographing all the joints on one side of the body and counting the number of centres which have ossified and, later, the number of epiphyses which have fused. This system involves many radiographic films and is therefore expensive; it also ignores the structural changes which occur in the epiphyses between their first appearance and their fusion with the diaphyses [1, 14, 31].

Fishman developed a system of skeletal maturation assessment (SMA) based upon skeletal maturity indicators (SMIs) demonstrated on hand-wrist radiographs for the assessment of the pubertal growth spurt. This sequence of events provides a methodological approach for identifying specific maturational stages that cover the entire adolescent period. The SMI is an organized and relatively simple way to observe skeletal maturity: it uses 11 anatomical sites on the phalanges, adductor sesamoid and radius, excluding the carpal bones [12].

Objectives of this Study

The aims of our study are as follows:

1. To assess the hand-wrist skeletal maturation in male and female adults
2. To assess the correlation between skeletal maturity stages and chronological age
3. To provide an idea for establishing an average skeletal age for selected population in relation to chronological age

Materials and Methods

The study consisted of collected 330 digital hand-wrist radiographs aged between 8 and 18 years, which are divided with an equal distribution of males (165) and females (165). Informed consent was taken from all the individuals who participated and the study was approved by ethical committee of GITAM Dental College and Hospital, Visakhapatnam, AP, India. All the children were apparently normal and belonged to the average middle class in their socio-economic status. Patients with serious medical illness and history of trauma to the hand and wrist region were excluded from the study. To

Table 1 Fishman's 11 skeletal maturity indicators

SMI 1		The proximal phalanx of third finger shows equal width of epiphysis and diaphysis
SMI 2		The middle phalanx of third finger shows equal width of epiphysis and diaphysis.
SMI 3		The middle phalanx of fifth finger shows equal width of epiphysis and diaphysis
SMI 4		Appearance of adductor sesamoid of the thumb.
SMI 5		Capping of epiphysis of distal phalanx on the third finger

avoid observer bias, each digital hand-wrist radiograph of an individual was coded with only a numerical identity number (1–330) to ensure that the examiners were blind to sex, name and age of subjects. Two examiners (two maxillofacial

orthodontists) were given CDs of the images and instructed to complete the staging for all images. To test the intraexaminer's reliability, each examiner unknowingly re-evaluated 30 of their images after 1 month.

Table 1 (continued)

SMI 6		Capping of epiphysis on middle phalanx on the third finger
SMI 7		Capping of epiphyses of middle phalanx on fifth finger.
SMI 8		Fusion between epiphysis and diaphysis of the distal phalanx on the third finger
SMI 9		Fusion between epiphysis and diaphysis of the proximal phalanx of the third finger.
SMI 10		Fusion between epiphysis and diaphysis of middle phalanx on the third finger.
SMI 11		Fusion of epiphysis and diaphysis seen in the radius.

Table 2 Descriptive statistics of age of both sexes of skeletal maturation indicator

SMI	Males			Females			Total		
	No. of cases	Mean	SD	No. of cases	Mean	SD	No. of cases	Mean	SD
1	24	10.17	1.59	16	9.98	1.40	40	10.09	1.50
2	25	12.00*	1.67	14	10.24*	0.99	39	11.37	1.68
3	19	12.91	1.93	7	11.62	1.63	26	12.56	1.91
4	6	11.22	1.34	12	11.12	1.18	18	11.15	1.20
5	18	13.33	2.25	12	12.13	1.32	30	12.85	1.99
6	10	15.35*	1.84	4	11.54*	1.28	14	14.26	2.43
7	12	15.56*	1.75	2	11.10*	1.40	14	14.92	2.31
8	3	16.71*	1.15	13	13.97*	1.86	16	14.48	2.04
9	5	16.26*	1.64	9	14.15*	1.53	14	14.91	1.84
10	17	17.11*	1.30	25	15.45*	1.58	42	16.12	1.67
11	26	18.11*	1.13	51	17.34*	1.67	77	17.60	1.54
TOTAL	165	14.12	3.17	165	14.01	3.18	330	14.06	3.17

* $p < 0.05$ is considered as significant

Assessment of the Staging of Skeletal Maturation Using Skeletal Maturity Indicators from Hand-Wrist Radiograph with Fishman's Method

To evaluate the maturational patterns of the indicators in the hand-wrist, Fishman's 11-grade system (1982) [12] was used (Table 1).

Statistical Analysis

The data was analysed using the Statistical Package for Social Science (SPSS) software, Version 20.0 (SPSS Inc., Chicago, IL, USA). The following statistical methods were employed in the present study:

1. Mean and standard deviation
2. Pearson correlation coefficient
3. Spearman's rank correlation coefficient
4. Student's t test (independent sampled t test)
5. Analysis of variance (ANOVA) test
6. Regression analysis

The following results were drawn from the statistical analyses.

Results

Digital hand-wrist radiographs which consisted of images from 165 males and 165 females whose ages ranged from 8 to 18 years were evaluated using Fishman's method. The SMI stages were recorded and analyzed with reference to mean CA. The mean and standard deviations for the SMI stages are described in Table 2. A significant difference in the chronological age was observed in descriptive statistics of age of both sexes for SMI stages. The mean difference in skeletal age of both males and females at SMI grades 2, 6, 7, 8, 9, 10, and 11 was found to be statistically significant at $p < 0.05$ respectively. A striking feature observed was that the maturational development for females was earlier than their male counterparts. The mean age for initiation of skeletal maturation was 10.17 ± 1.59 years for males and 9.98 ± 1.4 years for females (SMI 1). Females completed skeletal maturation at mean age of 17.34 ± 1.67 years and males completed at 18.1 ± 1.13 years (SMI 11). The F values of 44.60 for males and 55.76 for females were found to be significant at $p < 0.0001$ (Tables 3 and 4). A significant correlation was found between chronological age and skeletal maturation levels ($r = 0.82$). The relative chronological age distributions for the female and male skeletal maturity indicators are plotted in Figs. 1 and 2. This shows

Table 3 Analysis of variance of age of males of skeletal maturation indicator

Source of variation	Sum of squares	df	Mean square	F	Significance
Between SMI groups	1,225.823	10	122.582	44.596	.000
Within SMI groups	423.309	154	2.749		
Total	1,649.132	164			

Table 4 Analysis of variance of age of females of SMI

Source of variation	Sum of squares	df	Mean square	F	Significance
Between groups	1,299.489	10	129.949	55.758	.000
Within groups	358.911	154	2.331		
Total	1,658.401	164			

that the ages of occurrence of the SMI follow a gradual chronologic progression through the adolescent growth period. Regression formulas for males, females and the whole sample were derived to calculate skeletal age.

The formulation of regression equations are as follows:

Males: $\text{age} = 9.956 + 0.628 (\text{observer A1}) + 0.116 (\text{observer B1})$

Females: $\text{age} = 8.765 + 0.795 (\text{observer A1}) - 0.072 (\text{observer B1})$

Whole sample: $\text{age} = 9.687 + 0.730 (\text{observer A1}) - 0.046 (\text{observer B1})$

Significant inter- and intraobserver correlation coefficient of 91 and 98 % was observed. Spearman's rank correlation showed significant association between chronological age and skeletal maturation levels in females ($r = 0.86$) and males ($r = 0.84$) (Table 5). The reliability of intra- and interexaminer radiographic interpretation was indicated by high correlation between readings recorded by the two different examiners.

Discussion

The present study was conducted with an aim to assess the skeletal maturation level of an individual by interpretation of digital hand-wrist radiograph and to relate it with CA. In this study, skeletal maturation level for each subject was assessed using digital hand-wrist radiograph according to the Fishman's method [12]. This method offers an organized and relatively simple approach to determine the level of skeletal maturation from hand-wrist radiograph. We observed that a significant difference between mean values of CA and skeletal maturation in entire sample and it indicates that skeletal maturation is advanced than CA. There are some physiological events which take place during normal growth of bones. Many investigators, namely Tanner (1975) [33], Grave and Brown [34], Hagg and Taranger in 1980 [18], Fishman [12], and Abder Kader [22] have delineated several specific ossification stages that occur before, at or after peak height velocity. The identification of these skeletal maturation levels provides a useful means of identification of the specific points along the progressive path of adolescent growth.

Fig. 1 Graph showing correlation between CA and SMI stages in males

Fig. 2 Graph showing correlation between CA and SMI stages in females

Hand-wrist radiograph has its use long since to indicate the stage of skeletal maturity and predict the onset of maximum pubertal growth. The coexistence of a large number of ossification centres in a relatively smaller area with distinct and yet predictable sequence of maturation has made hand-wrist radiographs a useful clinical tool to assess skeletal maturity [2, 6, 7, 11, 17]. The hand-wrist radiograph has been one of the most popular biological indicators used by orthodontists to assess skeletal development. Todd stated that in an evenly maturing skeleton, any area would show the same maturation developmental status [34].

In the present study, a significant difference was observed to exist between SMI stages and their corresponding CA. A general trend observed was that as the mean bone age scores increased, their corresponding CA also increased linearly. A striking feature was that in male subjects, skeletal maturity was much slower as compared to female subjects of the same age groups. There was a significant difference between mean

values of chronological age and bone age in the entire sample and showed that bone age is advanced than CA, in support with Fishman et al. [11–13], Hunter [21], Schour and Masseler [30], and Kiran S et al. [24]. This finding indicates that Indian children tend to be late maturers when CA was used to indicate the skeletal maturity. The appearance of each skeletal stage was consistently earlier in the females than in the males, and this finding was in accordance with previous reports [6, 16, 26, 35].

In this study, females were advanced in skeletal maturation than males in all the age groups. This is supported by Hagg and Taranger [18], Koshy and Tandon [25], Prabhakar et al. [29], Bala M et al. [4], Hunter [21], Fishman [11–13], Joshi et al. [23], and Bhatia et al. [5]. The mean bone age was found to be constantly lower than the mean CA at all skeletal maturity stages (Table 2). A similar finding has been previously reported among Thai, Turkish and Saudi sample [2, 26, 35]. Conventional prediction indicators of maturation

Table 5 Spearman's rank correlation between Chronological age and skeletal maturation

		CA	SMI		
			Females	Males	Entire sample
Age of children (years)	Spearman's rank correlation	1	0.866**	0.842**	0.822
	Significance (two-tailed)		0.000	0.000	0.000
	N		165	165	

**Correlation is significant at the 0.01 level (two-tailed)

overestimate a child's developmental stage and, consequently, underestimate growth potential. Conversely, comparisons of a child's status with the published standards from other countries might overestimate the degree of developmental delay or precocity. Some variations were observed in the results pertaining to the chronological age for the initiation and completion of the active growth when compared to the study by Fishman [12] and Madhu et al. [28]. These variations could be attributable to the differences in sample sizes and the geographical, cultural, climatic and dietary differences which may influence the growth and maturity of children. It has, therefore, been suggested that separate standards should be available for children of different races and different regions. It has long been recognized that a person's chronologic age does not necessarily correlate well with his maturational age. One may be skeletally accelerated or delayed in terms of maturational development. There is a wide variation in the chronologic age pertaining to the onset and duration of the adolescent growth spurt for both males and females.

In this study, Fishman's method of skeletal maturation was used to assess skeletal maturation and significant correlation was found with CA ($r=0.82$) in entire sample. The simplicity of the Fishman's method and the use of distinct and clear skeletal maturity indicators perhaps may have contributed to the high reproducibility of the readings in our study. Also, digital imaging provided the highest quality and greatest flexibility of radiographs with less exposure to radiation. The limitations in the study include that the skeletal maturation assessment was done from only a part of skeleton which may or may not represent the whole skeleton and the greatest limit of the method seems to be the operator experience in determining the stages of development of skeletal maturity.

Conclusion

This study presents some of the basic relationships associated with skeletal maturation during adolescence, utilizing hand-wrist radiographs to facilitate the assessment of the average skeletal age of an individual. As stated in literature, healthy children of any age do not demonstrate any chronologic specificity regarding particular stages of maturation. Skeletal maturation assessment will provide a more reliable means of evaluating individualized maturational levels within very wide chronological age ranges.

Conflict of Interest Dr. Rezwana Begum Mohammed declares no conflicts of interest. Dr. M. Asha Lata Reddy declares no conflicts of interest. Dr. Megha Jain declares no conflicts of interest. Dr. Johar Rajvinder Singh declares no conflicts of interest. Dr. Praveen Sanghvi declares no conflicts of interest. Dr. Anshuj Ajay Rao Thetay declares no conflicts of interest.

Statement of Human and Animal Rights All procedures followed were in accordance with the ethical standards of the committee of GITAM Dental College and Hospital, Visakhapatnam, India.

Statement of Informed Consent Informed consent was obtained from all patients who are being included in the study.

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