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Research Article

COMPARISON OF RADIOGRAPHIC METHODS (THE GILSANZ AND RATIBIN ATLAS AND TANNER-WHITEHOUSE 2 AND 3) OF BONE AGE ASSESSMENT WITH CHRONOLOGICAL AGE

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ABSTRACT

Objective: Bone age assessment (BAA) can play an important role in legal and medical contexts. It can help determine a person's legal rights and responsibilities, and can also be used to estimate their chronological age (CA) when accurate birth records are not available. BAA is used in situations such as identification, employment, criminal responsibility, judicial punishment, consent for marriage, and in sports competitions. In addition, it can also be used in cases where there is a need to estimate CA, such as during immigration or in conditions where birth records are not available.

Methods: The study was approved by the Institutional Ethical Committee, and written consent was obtained from both children and their parents before participating in the study. Patients were selected based on specific inclusion and exclusion criteria. A data collection form was created for each participant. X-rays of the left hand and wrist were taken for all children referred to the X-ray Department at Sahyadri Speciality Hospital in Pune. The CA of the child was determined by their date of birth, and the bone age (BA) was assessed using radiographic methods.

Result: The Bland–Altman plot is a statistical tool used to compare the agreement between two methods of measurement, in this case, the CA and Tanner-Whitehouse 2 (TW3) methods for BAA. The results of the comparison showed a statistically significant agreement between the TW3 method and the GR atlas.

Conclusion: The TW2 method is not reliable for BAA. However, the TW3 method is considered reliable for assessing BA in older male children (ages 105–192 months) and younger female children (ages 13–104 months). On the other hand, the GR atlas appears to be more effective for younger male children (ages 13–104 months) and older female children (ages 105–192 months). In addition, the TW3 method can be used in conjunction with the GR atlas for older female children.

Keywords: Bone age, Medico legal, X-ray

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INTRODUCTION

Bone age assessment (BAA) is a clinical method for evaluating the stage of skeletal maturation of a child. It is often expressed as skeletal age assessment [1]. Child age can be assessed through two methods: Chronological age (CA) and bone age (BA). CA is determined by the child's birth date and represents their actual age. BA, on the other hand, assesses the maturation of bones and is a more accurate indicator of a child's growth development and maturation level. BA is determined by observing the appearance and maturation of specific ossification centers, which typically occur at specific times in a child's development. The development of bones goes through similar stages, each with its own distinct characteristics, allowing BA to provide a more accurate reflection of a child's growth and maturation.

BAA is a widely used radiological examination in pediatrics that compares a child's skeletal age (the age of their bones) with their CA (based on their birth date). A discrepancy between these two ages may indicate abnormal skeletal growth or hormonal imbalances. BAA is useful for monitoring the effectiveness of growth hormone therapy and for diagnosing endocrine disorders [2,3].

BAA has a range of applications beyond identifying differences between skeletal and CA. It is used in the diagnosis of familial short stature and constitutional growth delay, to interpret hormone levels during puberty, to diagnose precocious puberty or hyperandrogenism, and to make decisions about treatment for these conditions [4,5]. BAA is also used to predict adult height in normal children, evaluate children with growth and/or puberty disorders, and determine when to start replacement therapy in hypogonadism. Formulas have been created to calculate the final adult height of normal, healthy children based on their BA values.

It is also performed when surgery for correcting deformities of the long bones or the vertebral column is planned [6].

Assessment of BA can be performed using multiple bones in the body, such as the elbow, pelvis, clavicle, foot, shoulder, or ankle. However, these methods are not suitable or practical for researchers due to their high cost and the risk of exposure to radiation.

Radiographs of the hand and wrist are favored for BAA due to the presence of many bones and the ease of taking radiographs. In addition, radiation exposure from these radiographs is minimal, with a dose of 0.0001–0.1 mSv, which is <20 min of natural background radiation [7-9].

METHODS

The study was a prospective analysis and includes 120 radiographs of the left hand and wrist of all children who were referred to the X-ray Department at Pacific Institute of Medical Sciences, Udaipur. The standard posterioanterior (PA) view of the left hand and wrist was taken. The CA of the child was calculated from DOB. For assessment of BA, radiographic methods were used. The observations and results of the study were tabulated under various headings.

Our study compared the Tanner-Whitehouse 2 (TW2) method, TW3 method, and GR method of BAA. The correspondence of the skeletal age assessed by all systems with the CA of the studied individuals was also determined.

Data analysis

The data on categorical variables are shown as n (% of cases) and the data on continuous variables are presented as mean and standard deviation (SD). The inter-group comparison of categorical variables was done using Chi-square test or Fisher's exact probability test for 2 × 2 contingency table. The statistical significance of pair-wise difference of means of ages by four methods was tested using paired t test. The inter-group statistical significance of difference across three groups was tested using the analysis of variance (ANOVA – F test) technique [10]. The underlying normality assumption was tested before subjecting the study variables to the paired 't' test or ANOVA. Correlation analysis by Pearson's method was carried out to study the statistical significance of the linear relationship between the age data by four techniques. Bland–Altman's method was used to study the extent of agreement between the standard method (CA) and the test methods (TW2, TW3, and GR ATLAS) for the estimation of age. Linear regression analysis was used as a part of Bland–Altman's methodology to test the statistical significance of the extent of bias (difference in ages by two methods) present between the two methods of age estimation against the standard method (Chronological). Intra-class correlations were calculated to determine the agreement between each method of age estimation with the CA. The entire data were entered in MS Excel before its statistical analysis. The $p<0.05$ was considered to be statistically significant. All the hypotheses were formulated using two-tailed alternatives against each null hypothesis (hypothesis of no difference). The entire data were statistically analyzed using Statistical Package for Social Sciences (SPSS version 21.0, IBM Corporation, USA) for MS Windows [11,12].

RESULTS/OBSERVATION

A total number of 120 children with or without clinical history were radiographed for the left hand and wrist. After taking the consent of the children and parents, the date of birth was noted down. The standard PA view of the left hand and wrist was taken.

Sex distribution among study population

The children were divided on the basis of sex. Out of the study population of 120 children, 80 (66.6%) were male children and 40 (33.3%) were female children (Table 1).

Age distribution among study population

Radiographs were divided into two age groups of age 13–104 and 105–192 months based on CA for each gender (Table 2).

Radiographs were divided into two age groups of age 13–104 and 105–192 months based on CA for each gender (Table 3).

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 86 which correlates with a bone age of 12 months or less.

TW 3 method - The skeletal maturity score is 144 which correlates with a bone age of 54 months (Fig. 1a).

GR atlas - The radiograph which is closely matched corresponds to the age of 48 months and the radiograph is shown (Fig. 1b).

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 533 which correlates with a bone age of 105 months.

TW 3 method - The skeletal maturity score is 456 which correlates with a bone age of 148 months (Fig. 2a).

GR atlas - The radiograph which is closely matched corresponds to the age of 144 months and the radiograph is shown (Fig 2b).

Table 1: Sex distribution among study population

Sex	No. of cases (N=120)	Percentage
Male	80	66.6
Female	40	33.3

Table 2: Age distribution among male children

Age group (months)	No. of male children	Percentage
13–104 months	39	48.75
105–192 months	41	51.25
Total	80	100

Table 3: Age distribution among female children

Age group (months)	No. of male children	Percentage
13–104 months	39	48.75
105–192 months	41	51.25
Total	80	100

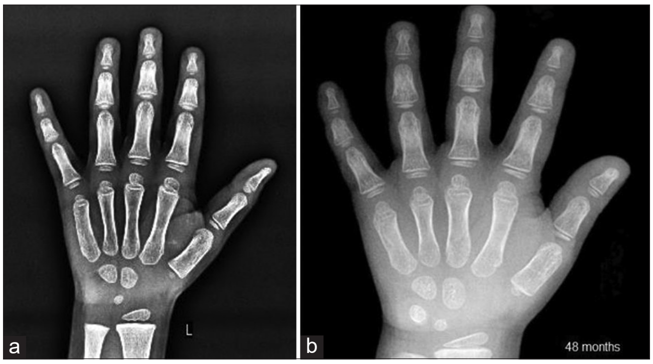

Fig. 1: (a and b) Case 1 - Radiograph of a male child of chronological age 42 months

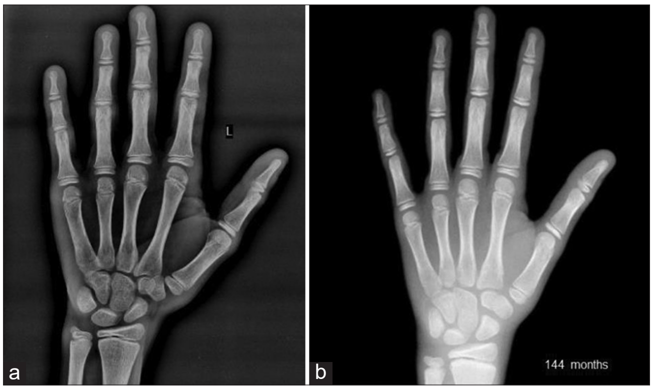

Fig. 2: (a and b) Case 2 - Radiograph of a male child of chronological age 148 months

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 221 which correlates with bone age of 28 months.

TW 3 method - The skeletal maturity score is 274 which correlates with a bone age of 67 months (Fig. 3a).

GR atlas - The radiograph which is closely matched corresponds to the age of 65 months and the radiograph is shown (Fig. 3b).

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 709 which correlates with bone age of 114 months.

TW 3 method - The skeletal maturity score is 628 which correlates with a bone age of 137 months (Fig. 4a).

GR atlas - The radiograph which is closely matched corresponds to the age of 132 months and the radiograph is shown (Fig. 4b).

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 28 which correlates with a bone age of 12 months or less.

TW 3 method - The skeletal maturity score is 53 which correlates with a bone age of 27 months (Fig. 5a).

GR atlas - The radiograph which is closely matched corresponds to the age of 28 months and the radiograph is shown (Fig. 5b).

Hence, age assessed by radiographic methods shows retarded bone maturation as compared to the chronological age of the child

Bone age as calculated by radiographic methods:- TW 2 method - The skeletal maturity score is 559 which correlates with a bone age of 92 months or less.

TW 3 method - The skeletal maturity score is 599 which correlates with a bone age of 132 months (Fig. 6a).

GR atlas - The radiograph which is closely matched corresponds to the age of 132 months and the radiograph is shown (Fig. 6b).

Hence, the age assessed by TW3 and GR atlas shows advanced bone maturation as compared to the chronological age of the child.

DISCUSSION

BAA is a method for evaluating the skeletal maturity stage of a child. Skeletal maturity is mainly assessed by the degree of development and ossification of the secondary ossification centers in the epiphysis.

It is used in the pediatric population to determine any discrepancy between skeletal age and CA. A difference between CA and skeletal age may suggest abnormalities in skeletal growth or hormonal problems. Assessment of the bone age of an individual is also important both for the medical jurist and lawyers.

TW2 method

It was observed that the mean BAA (shown in Table 4) by the TW2 method was smaller than the mean CA for both male and female age groups.

Bland–Altman plot (average vs. difference) was used for comparing the agreement between CA and TW2 methods for BAA. The limits of agreement are relatively wider with higher mean bias. The plot indicates that there is a systematic bias between the two methods (p=0.020 of beta coefficient for average, by linear regression method between difference and average by two methods, R^2-value=12.0%, as shown in Table 5). It is thus concluded that there is no statistically significant agreement (overall) between CA and TW2 methods for the assessment of age. However, the TW2 method shows good agreement in male (13–104 months age group) and female children (13–104 months age group). However, this agreement is poor compared to the GR atlas for males (13–104 months age group) and the TW3 method for females (13–104 months age group).

TW3 method

It was observed that the mean BAA (shown in Table 4) by the TW3 method was smaller than the CA for both male and female children of

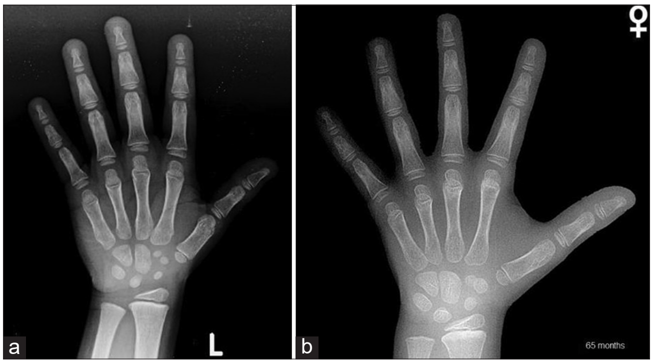

Fig. 3: (a and b) Case 3 - Radiograph of a female child of chronological age 59 months

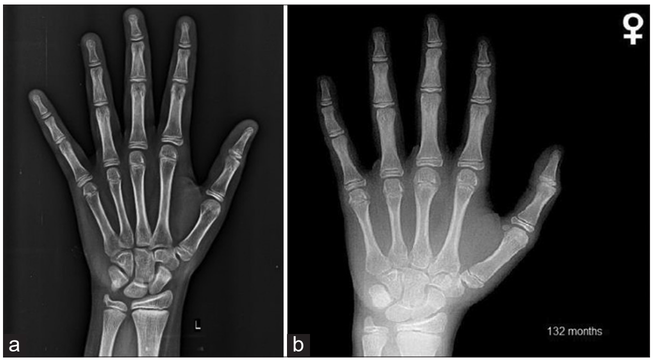

Fig. 4: (a and b) Case 4 - Radiograph of a female child of chronological age 139 months

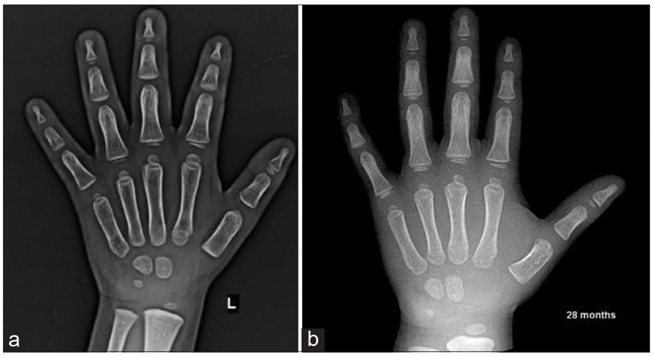

Fig. 5: (a and b) Case 5 - Radiograph of a male child of chronological age 144 months with a history of left to right shunt and short stature

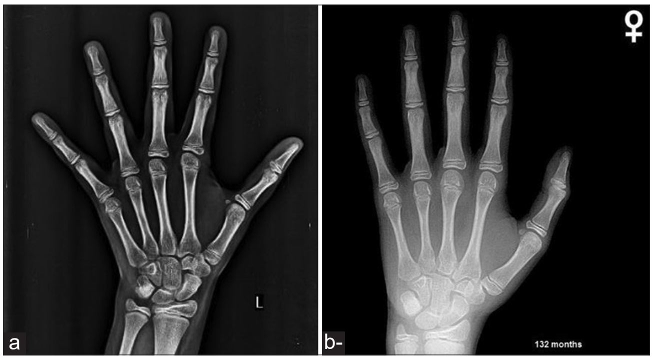

Fig. 6: (a and b) Case 6 - Radiograph of a female child of chronological age 101 months with a history of tall stature

Table 4: Distribution of sex-specific mean age by CA and radiographic methods of bone age assessment

Sex	Age group (months)	Age (months)							
		CA		TW2 method		TW3 method		GR atlas	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Male (n=80)	13–104 (n-39)	60.56	22.77	28.72	25.19	72.72	32.62	52.44	28.24
	105–192 (n=41)	153.39	21.19	119.44	38.11	15.49	28.66	1156.00	32.91
Female (n=40)	13–104 (n=26)	54.00	24.31	27.08	22.06	63.15	29.81	47.69	30.65
	105–192 (n=14	129.29	17.39	98.21	27.53	129.71	16.39	123.43	17.25
All (n=120)	13–104 (n=65)	57.94	23.44	28.06	23.82	68.89	31.65	50.54	29. 09
	105–192 (n=55)	147.25	22.75	114.04	36.69	147.7112 147.44	27.97	147.71	32.85

CA: Chronological age

Table 5: The linear regression analysis for the prediction of difference (bias) sing average of both the methods by Bland–Altman analysis

Sex	Age group (months)	Regression analysis for predicting Bias based on Average (Bland–Altman analysis)					
		CA and TW2 method		CA and TW3 method		CA and GR Atlas method	
		Beta-value (% R^2)	p-value	Beta-value (% R^2)	p-value	Beta-value (% R^2)	p-value
Male	13–104	−0.126 (1.6%)	0.447 ^{NS}	−0.395 (26.6%)	0.001***	−0.245 (9.7%)	0.054 ^{NS}
	105–192	−0.702 (37.4%)	0.001***	−0.377 (12.4%)	0.024*	−0.531 (24.9%)	0.001***
Female	13–104	0.1 08 (2.5%)	0.444 ^{NS}	−0.219 (13.8%)	0.062 ^{NS}	0.247 (18.5%)	0.028*
	105–192	−0.571 (24.7%)	0.050*	0.075 (0.5%)	0.804 ^{NS}	0.010 (0.0%)	0.971 ^{NS}
All	13–104	−0.020 (0.0%)	0.862 ^{NS}	−0.327 (22.0%)	0.001***	−0.239 (11.7%)	0.005**
	105–192	−0.571 (28.6%)	0.001***	−0.249 (6.9%)	0.052 ^{NS}	−0.428 (21.1%)	0.001***
All	All	−0.459 (12.0%)	0.020*	0.019 (0.2%)	0.630 ^{NS}	−0.025 (0.5%)	0.425 ^{NS}

Regression analysis with Bias as a DV and average as an IV. p<0.05 is considered to be statistically significant bias (systematic error). *p<0.05. **p<0.01, ***p<0.001, NS: Statistically non-significant, CA: Chronological age

age group 13–104 months. While the mean BA is almost similar to the mean CA for male and female children age group 105–192 months.

The limits of agreement are relatively narrower with lower mean bias. The plot indicates that there is no systematic bias between the two methods (p=0.630 of beta coefficient for average, by linear regression method between difference and average by two methods, R^2-value=0.2%, (as shown in Table 5).

It is thus concluded that there is a statistically significant agreement (overall) between CA and TW3 methods for the assessment of age. However, the TW3 method shows good agreement in female children of age group 13–104 months and 105–192 months. However, for female children of age group 105–77 192 months, the GR atlas (p=0.971) is even better than the TW3 method (p=0.804) for assessment of age.

GR atlas

It is observed that the mean BAA (shown in Table 4) by the GR atlas method is slightly smaller than the mean CA for female age groups (13–104 months and 105–192 months) and male age group of 13–104 months, whereas the mean BA is slightly higher to the mean CA for male children in the age group of 105–192 months. The limits of agreement are relatively narrower with lower mean bias. The plot indicates that there is no systematic bias between the two methods (p=0.425 of beta coefficient for average, by linear regression method between difference and average by two methods, R^2-value=0.5%, as shown in Table 5).

It is thus concluded that there is a statistically significant agreement (overall) between CA and GR atlas methods for the estimation of age. However, the GR atlas method shows good agreement in male children (13–104 months age group) and female children (105–192 months age group).

CONCLUSION

In our prospective, observational, and comparative study of 120 children, the following conclusions were drawn:-

- Radiographs of the hand and wrist are suitable for BAA because it possess many bones and taking radiographs of the hand and wrist is easy and also gives least radiation exposure.
- BAA is helpful in the monitoring of growth hormone therapy and diagnosis of endocrine disorders and is also important for medical jurists and lawyers.
- TW 2 method is not reliable for the assessment of BA. TW3 method is reliable for assessing BA in older male children (105–192 months) and female children (13–192 months).
- GR atlas is useful in younger male children (13104 months) and older female children (105–192 months).

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AUTHORS' CONTRIBUTIONS

Conceptualization, data handling, experiments design, data analysis, provision of study materials and equipment, study validation, supervision, data presentation, draft preparation, study consultation was done by Dr. Sunil Kast, Dr. Yogesh kumar sharma, Dr Ankit Chauhan The writing and reviewing, project administration was done by Dr. Rajesh Suwalka, Dr. Mukund Rahalkar.

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COMPETING INTERESTS

The authors declared no conflict of interest.

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