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Age Estimation: A Comparison of Dental and Skeletal Radiological Assessed Age with Chronological Age in Individuals Presented to Forensic Medicine Department Khyber Medical College Peshawar: A Cross Sectional Study

Muhammad Asghar Khattak[1], Hakim Khan Afridi[2], Rabia Khan [3], Farhan Ahmad Alizai[4], Sumbal Javed[5], Iftikhar Ahmad[5], Mahnoor Ali[2]

1. Department of Forensic Medicine and Toxicology, Kabir Medical College, Peshawar, Pakistan
2. Department of Forensic Medicine and Toxicology, Khyber Medical College, Peshawar, Pakistan
3. Department of Forensic Medicine and Toxicology, Kohat Institute Of Medical Science, Kohat, Pakistan
4. Department of Forensic Medicine and Toxicology, Gomal Medical College, Dera Ismail Khan, Pakistan
5. Department of Forensic Medicine and Toxicology, Khyber Girls Medical College, Peshawar, Pakistan

Abstract

Background: Age estimation is a critical aspect of forensic and legal investigations, especially in populations where documentation is unreliable or absent. Among the most reliable biological indicators for assessing age are dental and skeletal radiological methods. However, their accuracy can vary across populations due to differences in ethnicity, nutrition, and socio-economic status.

Objective: To compare dental and skeletal radiologically assessed age with actual chronological age in adolescents and young adults from Peshawar, Pakistan, and to determine which method offers greater accuracy, reliability, and agreement with known age.

Methods: This cross-sectional study included 150 participants (80 males, 70 females) aged 8 to 20 years. Dental age was determined using Demirjian's method and modified form from orthopantomograms, and skeletal age was assessed using hand-wrist radiographs interpreted via the Greulich and Pyle Atlas. Statistical analyses included mean absolute error (MAE), paired sample t-tests, Pearson correlation coefficients, to assess method accuracy, correlation, and reproducibility.

Results: The mean chronological age was 14.2 ± 3.1 years. Dental age (mean: 14.6 ± 2.9 years) showed a tendency to overestimate chronological age (MAE: 0.75 years), whereas skeletal age (mean: 14.0 ± 2.8 years) demonstrated a closer agreement (MAE: 0.45 years). Skeletal age had a stronger correlation with chronological age ($r = 0.91$, $p < 0.001$) compared to dental age ($r = 0.85$, $p < 0.001$). The skeletal method also maintained better consistency across age groups, particularly in the 16–20 years bracket. Gender-based differences were minimal and statistically insignificant. Both methods showed excellent inter-rater reliability (ICC > 0.89).

Conclusion: Skeletal radiological age assessment using the Greulich and Pyle Atlas demonstrates superior accuracy and correlation with chronological age compared to dental age estimation via Demirjian's method in the adolescent population of Peshawar.

Keywords: Age estimation, Dental age, Skeletal age, KPK.

Introduction

Estimation of age forms an important aspect of forensic medicine, legal investigations, anthropological assessments, and pediatric endocrinology. Precise age determination may be of help in identifying unknown bodies, confirmation of age for asylum, adoption, or sports eligibility, and treatment guidance in pediatric patients. In living individuals, especially adolescents and young adults, chronological age is not a true indicator of biological maturity for various environmental, nutritional, and genetic reasons.[1]

Precise age estimation plays a cardinal role in forensic science, anthropology, paediatrics, and legal medicine. With greater cross-border migration, juvenile cases, and unregistered births in different parts of the world, determination of age has become important not only for identification purposes but also in issues related to criminal liability and human rights. Of the many biological indicators, radiological assessments of dental and skeletal maturity have emerged as tools of choice for age estimation when chronological data is either missing or in dispute.[2,3]

Among the various age estimation methods, dental and skeletal radiological assessments are two of the most commonly used. Skeletal age is normally assessed with the use of ossification patterns of certain bones, usually the hand-wrist or clavicle, by X-ray examination, while dental age relies on the developmental stages of teeth, most commonly assessed through orthopantomograms (OPGs) using methods such as Demirjian's or Willems' criteria [4,5]. Each method has its own

Corresponding Author:
Iftikhar Ahmad
Department of Forensic Medicine and Toxicology, Khyber Girls Medical College, Peshawar, Pakistan
Email: iftikhar0912@gmail.com

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advantages and limitations, and their accuracy may vary across populations due to ethnic and geographical differences [6].

The need for reliable methods of age estimation is most urgent in Asia, which hosts more than half of the world's population. Cases of child labour, human trafficking, and refugee crises have brought forth increased interest in scientific methodologies to quantify age in the absence of documentation. Radiological techniques have become increasingly employed across Asian nations such as India, China, and Bangladesh, but variations in skeletal and dental development within different geographical locations bring home the need for regional population data to refine the accuracy.[7,8]

Age estimation is of growing importance in both civil and criminal justice systems within the jurisdiction of Pakistan. Recorded versus actual age discrepancies are commonly noted in cases related to child marriage, school admissions, employment verification, and criminal trials. Despite the relevance, there is a lack of updated, population-specific reference standards for radiological age estimation. Most studies are based on Western standards, which may not be wholly applicable to the Pakistani population due to ethnic, nutritional, and genetic reasons influencing growth and maturation.[9,10]

More precisely, zooming into the province of Khyber Pakhtunkhwa (KPK), a region marked by ethnic diversity, socio-economic challenges, and sparse health facilities, the issue becomes even more complex. The applicability of age estimation finds its prime relevance in medico-legal cases presented in government hospitals, where non-registration of births and non-maintenance of correct age records are aplenty. Yet, KPK remains underrepresented in national forensic research, leading to reliance on generalized data which may not reflect the developmental patterns of its unique demographic.[11]

Focusing on Peshawar, the provincial capital and a major hub for medico-legal casework, there is an urgent need for scientifically validated age estimation techniques. The medico-legal units of the city, such as those in Khyber Medical College and its affiliated hospitals, come across age-disputed cases quite often. In such cases, other than radiological assessments using dental and skeletal indicators, no tools are available to estimate biological age. However, the correlation between radiologically assessed age and actual chronological age within this specific population remains under-explored.[12]

Comparing these radiological methods with actual chronological age has allowed the validation and calibration of existing age estimation techniques in specific populations, which is a necessity to attain forensic accuracy and medico-legal reliability.[13]

Accuracy of age estimation methods is of prime importance in forensic cases where the age of an individual has legal implications, such as criminal responsibility, marriageability, and immigration disputes. The literature reports variability in the precision of both dental and skeletal methods in different populations. Only a few studies have been carried out in our regional population to establish which method gives an estimate closest to the chronological age.[14,15]

Understanding their reliability and precision, particularly in a comparative framework, can pave the way toward enhancing the medico-legal utility of dental and skeletal age estimation techniques. This study sets out to help bridge this gap by comparing dental and skeletal radiological age estimation directly to chronological age in individuals of known age and thus provides region-specific validation data.[16]

The primary objectives of this study is to compare dental and skeletal radiologically assessed age with chronological age in individuals and to determine which radiological method (dental or skeletal) provides age estimates closer to chronological age and To assess the correlation between each method and the actual age.

Methodology

This cross-sectional study was conducted in the Department of Forensic Medicine, Khyber Medical College, Peshawar, from 1st January 2025 to 30th June 2025 and ethical approval was obtain from Khyber medical college under ethical approval number 1070-tme-kmc The study population consisted of individuals aged 8 to 20 years. Participants of both genders within the specified age range were included in the study. Individuals with incomplete or unreliable documentation regarding their age were excluded.

This cross-sectional study included 150 participants aged 8–20 years from Peshawar, selected through convenience sampling. Demographic information and verified dates of birth were recorded to determine chronological age. Dental age was assessed using orthopantomograms and Demirjian's method, while skeletal age was evaluated through left hand-wrist radiographs of patients presented to forensic department Khyber medical college for age estimation using the Greulich and Pyle Atlas. All radiographs were examined independently by two trained observers. A structured proforma was used to record findings systematically. Quality control measures were applied to ensure accuracy and reliability.

Collected data were entered and analyzed using SPSS software. Descriptive statistics, including mean and standard deviation, were calculated for chronological, dental, and skeletal ages. Mean Absolute Error was used to assess the accuracy of both methods. Paired sample t-tests compared estimated ages with chronological age. Pearson correlation coefficients evaluated the relationship between methods and actual age. Inter- and intra-observer reliability were assessed using Intraclass Correlation Coefficients. A p-value of less than 0.05 was considered statistically significant.

Results

The sample consisted of 150 healthy individuals, 80 males and 70 females, in the age group of 8 to 20 years. The chronological age of the sample population under study is 14.2 ± 3.1 years. Dental age was estimated using Demirjian's method and modified Demirjian method from orthopantomograms, while skeletal maturity was assessed from hand-wrist radiographs interpreted using the Greulich and Pyle Atlas.

The determined mean dental age was 14.6 ± 2.9 years, while the mean skeletal age equaled 14.0 ± 2.8 years. When referring to the true chronological age, the dental age showed an MAE of 0.75 years, with a trend to slight overestimation, while the skeletal age had an MAE of 0.45 years with greater approximation to the real age.

Similarly, the results from statistical analysis by using paired sample t-tests showed that the difference between chronological age and dental age was significant at p=0.02, while there was no significant difference between chronological and skeletal age at p = 0.41. In addition, correlation analysis showed that the linear relationship of chronological age with skeletal age was stronger, r = 0.91, p <0.001, as opposed to dental age, r = 0.85, p < 0.001. These findings suggest that skeletal age estimation demonstrated slightly higher accuracy compared with dental age estimation

in this study population.

The present study's gender-specific analysis also indicated that the skeletal method was marginally showed higher accuracy for both genders, though these differences were not significant. In males, the MAE for skeletal age was 0.42 years, while in females it was 0.48 years. The MAE for dental age was 0.81 years in males and 0.68 years in females.

The age group-specific analysis revealed that in the 8-12 years age group, dental age tended to overestimate the chronological age by almost 0.9 years. In the 13-15 year olds, both methods presented moderate variability. However, skeletal age estimation did agree more closely with chronological age in the group of 16-20 year olds, thus reaffirming its reliability in older adolescents.

The inter-rater reliability for both methods was high: the ICCs were 0.89 for dental and 0.93 for skeletal assessment, reflecting excellent reproducibility of the radiological interpretations.

These findings indicate that skeletal radiological age assessment is more accurate, consistent, and in agreement with chronological age determination, particularly in the adolescent population of Khyber Pakhtunkhwa.

Table 1: Radiological Age Assessment Parameters

Parameter	Value
Mean Chronological Age	14.2 ± 3.1 years
Mean Dental Age	14.6 ± 2.9 years
Mean Skeletal Age	14.0 ± 2.8 years
MAE (Dental)	0.75 years
MAE (Skeletal)	0.45 years
Correlation with Chronological Age (Dental)	$r = 0.85$, $p < 0.001$
Correlation with Chronological Age (Skeletal)	$r = 0.91$, $p < 0.001$

Table 2 Gender Based Distribution of Dental & Skeletal Age

Group	Dental MAE	Skeletal MAE	P-Value
Males (n=80)	0.81	0.42	$p \approx 0.03$
Females (n=70)	0.68	0.48	$p \approx 0.12$

Table3: Age-Group Wise Comparison of Radiological Age Estimation Methods

Age Group (Years)	Sample Size (n)	Mean Chronological Age (Years)	Mean Dental Age (Years)	Mean Skeletal Age (years)	MAE Dental (Years)	MAE Skeletal (Years)
8–12	50	10.1 ± 1.3	11.0 ± 1.4	10.3 ± 1.2	0.90	0.50
13–15	55	14.0 ± 0.9	14.3 ± 1.1	14.1 ± 1.0	0.60	0.48
16–20	45	17.6 ± 1.2	17.8 ± 1.3	17.5 ± 1.1	0.55	0.35

Discussion

Age determination accurately has continued to play important roles in forensic medicine and legal medicine, as well as in pediatric health care. The need for determination of age accurately arises when the chronological age is not documented or disputed.[17] The current study has been planned to determine the chronological age and compare it with the dental and skeletal age of Pakistani youth in the city and province of Peshawar, Khyber Pakhtunkhwa.

These data suggest that the radiological assessment of the skeleton provides an estimation of the chronological age much closer than that of dental ages. The mean absolute error for the skeletal assessment was lower at 0.45 years, whereas for the dental assessment it was at 0.75 years, and this difference has been emphasized by other studies for highlighting the utility of the skeletal maturity assessment as a biological indicator of age in late puberty and adolescence [3,12,14,18].

The high correlation coefficient ($r = 0.91$) for skeletal age and chronological age is consistent with data observed in other studies conducted on Asian populations, specifically in India and Bangladesh, whereby the accuracy of methods utilizing skeletal evidence of ossification of the hand/wrist and clavicle bone has been validated on people of known ages [12,18]. Conversely, the dental method of estimating ages, although relatively accurate ($r = 0.85$), was prone to overestimation, specifically among younger individuals (ages 8-12 years), in agreement with data observed in validation tests among non-European populations on the Demirjian method [3,14].

This disparity could be attributed to ethnic and dietary influences in the process of dental development, given that the original method of Demirjian was formulated based on a French-Canadian population, which cannot be used in the same manner for the South Asian population because of the variation in ethnic backgrounds and dietary habits [3,16]. In addition, the process of dental development is less affected by environmental stress in comparison with skeletal development, and this can be a possible explanation for the ine accuracy of the estimates obtained from the method in the regions of KPK, which lack socioeconomic prosperity and nutritive elements, due to the stress they had been exposed to in the past.[13]

Their skeletal approach employing the Greulich and Pyle Atlas proved more accurate, especially in the age group of 16-20 years. This brings credence to the continued usage of this method in forensic medicolegal analyses in individuals who are on the threshold of adulthood.[9] It would, however, again be pertinent on this juncture to state that Greulich & Pyle standards are actually based on a North American Caucasian population, thuspossibly engendering some minor inaccuracies in cross-continental individuals of different ethnicity as well [2,15].

Based on these considerations, a gender analysis was conducted to see whether skeletal estimation methods were marginally more accurate in males or females. The result showed that skeletal estimation was marginally more accurate in males than females; however, the result was insignificant.[19] The result aligns with various research papers that take into account sex differences in the rate of growth and maturity at puberty [20]. A high inter-rater reliability was found to be 0.89 or higher in both methods.

One of the major advantages of this research study is its specificity to the region, and it targets a particular demographic, which is largely unrepresented in the available forensic literature. [11]The current norms and standards are based on the Western demographic, and therefore, there is a great need for demographic-specific data.[10] The current study fills this gap and the need for localized data within the field of forensic analysis.

However, there are some limitations of the study. The sample was not very large, but it was sufficient. Secondly, the study might not have included all the demographics of the people living in the province of Khyber Pakhtunkhwa. Moreover, the factors of nutritional status, socio-economic status, and the stage of puberty could significantly affect the rates of maturation, but they were not included in the control variables.[21]

Conclusion

The study concludes that skeletal age estimation is more accurate and reliable than that based on dental methods in adolescents and young adults from Peshawar. Both techniques have great forensic importance; however, skeletal estimations appear to be more in tune with biological maturity and should be given precedence when there is a need for an accurate age

estimation. Moreover, the local calibration of the existing techniques should not be underestimated to increase the accuracy and legal validity in different populations.

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Author Contributions

1. Muhammad Asghar Khattak: Conceptualization of the study, Data Analysis and Fundings.
2. Hakim Khan Afridi: Study design, Development of research methodology and Data Collection.
3. Rabia Khan: Conceptualization of the study, Data collection, Article writing, and Critical Review.
4. Farhan Ahmad Alizai: Fundings, Development of research methodology and Literature Review.
5. Sumbal Javed: Supervision, Data Analysis and Article writing.
6. Iftikhar Ahmad: Supervision, Data Analysis and Article writing.
7. Mahnoor Ali: Data collection, Study design, and Critical review of the manuscript