



Dental Age Estimation Methods in the Pakistani Population: A Scoping Review

Khan, Amber^{1,2*}; Yaqoob, Bakhtawar²; Franco, Ademir^{1,4}

¹ Division of Forensic Dentistry, Sao Leopoldo Mandic, Campinas 13045-755, SP, Brazil

² Department of Forensic Dentistry, Abbottabad International Medical Institute, KPK, 22020, Pakistan

³ Department of Science of Dental Materials, Rawal Institute of Health Sciences, Islamabad, Pakistan

⁴ Department of Therapeutic Stomatology, Institute of Dentistry, Sechenov University, Moscow, Russia

*Corresponding author: amberkhan.fo@outlook.com

KEY WORDS

Age Estimation by Teeth; Forensic Dentistry; Pakistani

ABSTRACT

Background: Dental age estimation can be a valuable tool of Forensic Odontology to support human identification and to assist the judicial system in criminal and civil cases that involve asylum seekers, violence against children, legal liability, among others. Population-specific reference studies are important in this field to promote evidence-based decisions and help experts find appropriate methods for dental age assessment. Understanding the current body of work in dental age estimation remains necessary to guide Pakistani forensic practice. **Objectives:** The purpose of this study was to screen the scientific literature and to find the studies that have been performed with different age estimation methods that have been applied to the Pakistani population over the years. **Methodology:** A scoping literature review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA-ScR) by searching the following online databases: PubMed/Medline, Scielo, Lilacs, ScienceDirect, Open grey and Open Access Thesis and Dissertations (OATD). Only original and analytical studies were considered. Two independent reviewers conducted data search, selection and extraction followed by a third expert. **Results:** A total of 1771 articles were detected and screened based on abstract and title reading. Eight articles published between 2012 and 2023 were included as eligible studies in this scoping literature review. The dental age estimation methods identified in this review covered bidimensional radiographic analysis of dental development through staging techniques (such as Demirjian's, Nolla, Willem's and Kohler's methods), volumetric analysis of the pulpal space through Cone Beam Computed Tomography scans, application of aspartic acid racemization and the macroscopic analysis of teeth ex vivo for destructive and non-destructive invasive methods. **Conclusion:** Although research on dental age estimation in Pakistan demonstrates a clear interest from the academic community (half of the eligible studies being published in the last five years), the current body of evidence is weakened by methodological shortcomings. Differences in study design, limited and uneven sample representation, and inconsistent use of standardized protocols hinder comparability across studies and compromise the generalization of the results. Addressing these limitations in future investigations will be essential to produce robust, population-specific reference standards and to enhance the forensic and clinical value of dental age estimation in the Pakistani context.

1. INTRODUCTION

Harvey [1] states that “probably the best definition of Forensic Odontology” is the one by Keiser-Nielsen [2]: “the proper handling and examination of the dental evidence, in the interests of justice, so that the dental findings may be properly presented and evaluated.” [2] Forensic Odontology plays an important role in the identification of victims from mass disasters [3], bite mark analysis [4], assessment of age [5,10-12], among other applications. In the context of mass disasters, for instance, comparative dental analysis is recognized by the International Criminal Police Organization (INTERPOL) as a primary method for human identification. In research, this is a growing field with scientifically reliable tools already consolidated for practice – among these tools, dental age estimation stands out as an important resource in the armamentarium of forensic odontologists. [13]

The age of an individual is expressed chronologically, which is represented by the difference between a specific point in time and birth. [12] However, the inherent intrinsic and extrinsic factors to which an individual is exposed in this interval may influence biological age differentiating it from chronological age. [14] When chronological age is unknown, and dental age

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estimation is performed, the biological age can be assessed.[15] Age assessment is often required in civil and criminal courts, for example in cases of asylum seekers, adoptions, clandestine immigration, human trafficking, sentencing of suspected juvenile offenders, sports practices, identification of unknown bodies, and judicial claims for retirement and pension. [12, 14, 16]

Dental age estimation is a scientific process that assesses the age of an individual by evaluating the development of teeth of children, adolescents and young adults. [17] In adults, teeth also can be used for age estimation, but age-related parameters change from progressive features (such as eruption and development) to regressive ones (normally attrition, periodontosis, deposition of secondary dentin, cementum apposition, root resorption and translucency). [10] Because of the different parameters available for age assessment and the distinct target populations (children, adolescents and adults) where dental age can be investigated, there are several methods reported to this end. [18, 19] Different subdivisions can be inferred, but dental age estimation methods are normally radiological (to assess dental development and eruption), morphological/histological (to assess regressive changes in adults) and biochemical. The applicability of these methods differs for the living and deceased [20, 21]. This is because some of the methods can be invasive (e.g. requiring extraction of the tooth from the alveolar socket) and destructive (requiring slicing or pulverization of the sampled tooth). [9, 22, 23, 24]

According to the Pakistan Bureau of Statistics census for the year 2023 (most recent), the population in the country was about 241.49 million with 51.48% being males and 48.51% females. According to Bureau of Emigration and Overseas Employment, a total of 663.186 Pakistanis left the country for employment in the year 2024. Among the Pakistanis who apply for asylum, only 15% were successful. According to an estimate, a total of 1.7 million illegal immigrants were still living in the country as of January 2024. [25] This scenario highlights the pressing importance of developing dental age estimation research using Pakistani samples. National reference data would be highly valuable in strengthening forensic practice, particularly in contexts where age assessment is legally or administratively required. Such data could support migration and asylum procedures, assist in the verification of age for overseas employment candidates, and contribute to the management of cases involving undocumented or illegal residents. Beyond migration issues, reference standards are equally relevant for criminal investigations, humanitarian forensic applications, and the protection of minors in vulnerable situations, including victims of trafficking, exploitation, or conflicts in war zones. Hence, understanding the current body of knowledge on dental age estimation within the Pakistani population is important to guide future studies and to optimally concentrate academic research efforts.

While Pakistan faces an urgent need to strengthen its forensic sciences as a whole, the development of forensic odontology—particularly its applications in age estimation—remains a critical area of focus. Equally important is the dissemination of knowledge through scientific communication, which helps raise awareness and foster professional engagement. Forensic odontology is not officially recognized as a specialty in the country, and awareness of the field was reported to be very limited, if not virtually absent, a decade ago [26]. Moreover, formal training in Forensic Odontology is only available abroad. In recent years, however, progress has been made as new experts have trained abroad and returned to Pakistan, contributing to the creation of a stronger body of evidence. Their efforts have introduced innovations and practical solutions that are gradually shaping forensic odontology training and raising awareness at both academic and professional levels. As a derived benefit, dedication to research on age estimation also strengthens related fields with shared interests, such as legal medicine and, clinically, orthodontics and pediatric dentistry. This overlap serves as an additional justification for advancing research on the topic.

The purpose of this scoping review was to I) screen the scientific literature to detect studies that have been performed in the field of dental age estimation in the Pakistani population, and II) to understand what the current body of knowledge for dental age estimation research and practice in the country is.

2. METHODOLOGY

Study Design and Ethical Aspects

A scoping review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses with an extension for Scoping Reviews (PRISMA-ScR).[27] Registration of the research protocol was accomplished in Open Science Framework (doi: 10.17605/OSF.IO/QAHB5).

Research Question and Eligibility Criteria

The research question was based on the acronym PCC (Population [P] – Pakistani individuals, Concept [C] – methods already tested in the target population, and Context [C] – forensic dental age estimation of children, adolescents and adults). The inclusion criteria consisted of observational analytical and cross-sectional studies. No restriction of year (from inception to search date), language or status of publication (e.g., ahead of print) was applied. The exclusion criteria were studies that 1) were not addressing the Pakistani population or combined samples of Pakistani and other populations, 2) were not testing dental age estimation methods, 3) solely based on tooth eruption (as this is not encouraged as sole approach for forensic dental age estimation), 4) solely compared intra and inter-observer reproducibility (not focusing on method's performance to estimate the chronological age), 5) and mixed research models or unclear methodological description.

Sources of information and search

Primary data sources were PubMed/Medline, SciELO, LILACS and ScienceDirect. Other online databases such as Open Grey and OATD were also used to partially retrieve the “grey literature” and minimize selection and publication bias. Medical Subject Headings (MeSH) and Descriptors in Health Sciences (DeCS) were used to build-up a search strategy. Boolean operators “AND” and “OR” were implemented to combine terms in two categories: (1) “Dental” OR “Odontology” OR “Dentistry” OR “Teeth” OR “Tooth” OR “Oral” AND “Age” AND (2) “estimation” OR “determination” OR “assessment” AND “Pakistan” (Table 1). The search was performed in February and March 2024. Unavailable full texts were requested to their corresponding authors via e-mail, awaiting seven days for a reply followed by a request through ResearchGate™ (Berlin, Germany) considering an additional period of seven days. A final attempt included the activation of an interlibrary Bibliographic Commutation Program (COMUT network).

Database search	Search Strategy
PubMed/Medline https://pubmed.ncbi.nlm.nih.gov/	("dental health services"[MeSH Terms] OR ("dental"[All Fields] AND "health"[All Fields] AND "services"[All Fields]) OR "dental health services"[All Fields] OR "dental"[All Fields] OR "dentally"[All Fields] OR "dentals"[All Fields] OR ("shigaku"[Journal] OR "odontology"[Journal] OR "odontology"[All Fields]) OR ("dentistry"[MeSH Terms] OR "dentistry"[All Fields] OR "dentistry s"[All Fields]) OR ("teeth s"[All Fields] OR "teeths"[All Fields] OR "tooth"[MeSH Terms] OR "tooth"[All Fields] OR "teeth"[All Fields] OR "tooth s"[All Fields] OR "tooths"[All Fields]) OR ("teeth s"[All Fields] OR "teeths"[All Fields] OR "tooth"[MeSH Terms] OR "tooth"[All Fields] OR "teeth"[All Fields] OR "tooth s"[All Fields] OR "tooths"[All Fields]) OR ("mouth"[MeSH Terms] OR "mouth"[All Fields] OR "oral"[All Fields])) AND ("agrosyst geosci environ"[Journal] OR "age"[Journal] OR "age omaha"[Journal] OR "age dordr"[Journal] OR "adv genet eng"[Journal] OR "age"[All Fields]) AND ("estimability"[All Fields] OR "estimable"[All Fields] OR "estimate"[All Fields] OR "estimated"[All Fields] OR "estimates"[All Fields] OR "estimating"[All Fields] OR "estimation"[All Fields] OR "estimations"[All Fields] OR "estimator"[All Fields] OR "estimator s"[All Fields] OR "estimators"[All Fields] OR ("analysis"[MeSH Subheading] OR "analysis"[All Fields] OR "determination"[All Fields] OR "determinant"[All Fields] OR "determinants"[All Fields] OR "determinate"[All Fields] OR "determined"[All Fields] OR "determinates"[All Fields] OR "determinating"[All Fields] OR "determinations"[All Fields] OR "determine"[All Fields] OR "determined"[All Fields] OR "determines"[All Fields] OR "determining"[All Fields]) OR ("assess"[All Fields] OR "assessed"[All Fields] OR "assessment"[All Fields] OR "assesses"[All Fields] OR "assessing"[All Fields] OR "assessment"[All Fields] OR "assessments"[All Fields])) AND ("pakistan"[MeSH Terms] OR "pakistan"[All Fields] OR "pakistan s"[All Fields])
SciELO http://www.scielo.org/	[(Dental OR Odontology OR Dentistry OR Teeth OR tooth OR Oral) AND (Age) AND (estimation OR determination OR assessment) AND (Pakistan)]
LILACS http://lilacs.bvsalud.org/	(dental OR odontology OR dentistry OR teeth OR tooth OR oral) AND (Age) AND (estimation OR determination OR

	assessment) AND (pakistan) AND db ("LILACS") AND instance "lilacsplus"
ScienceDirect https://www.sciencedirect.com	(Dental) AND (Age) AND (estimation OR determination OR assessment) AND (Radiograph) AND (Pakistan)
Open Grey http://www.opengrey.eu/	(Dental OR Odontology OR Dentistry OR Teeth OR Tooth OR Oral) AND (Age) AND (estimation OR determination OR assessment) AND (Pakistan)
OATD https://oatd.org/	(Dental OR Odontology OR Dentistry OR Teeth OR Tooth OR Oral) AND (Age) AND (estimation OR determination OR assessment) AND (Pakistan)

Table 1. Databases and Search Strategies.

Selection of Studies

Initially, the studies were imported to EndNote Web™ (Clarivate, London, UK) for the detection and exclusion of duplicates. The articles then were selected in a three-step process: title, abstract and full-text reading. Each step was accomplished independently and sequentially by two reviewers (AK and BY, both participating in all the following phases). Literature that did not conform with the inclusion criteria was excluded by preliminary screening which involved titles and abstract reading. In case of disagreements during title and abstract reading a third reviewer (AF) was recruited. Studies with missing abstracts were maintained to the next selection phase. Afterwards, full text reading was performed to identify the studies that fully met the inclusion criteria. During the selection of articles, the reviewers were not blind to the authors and journals of publication.

Data Extraction and Analysis

The following information were extracted: (I) general information of the eligible studies: authorship, year of publication, name of the journal, journal ranking in Scimago, the country where the study was carried out; and (II) specific information: population, sample size, sex, the age interval of the sample (minimum and maximum ages), observers for each method and methods used for age estimation. In order to establish standards for data extraction, two reviewers were requested to extract the data from an eligible study under the supervision of a third reviewer. Data were analyzed based on narrative and descriptive findings of the eligible studies in order to understand how dental age estimation has been researched in Pakistan and how the available methods have performed in the Pakistani population.

Article	Journal Name	Author	Year
Dental age table for a sample of Pakistani children	European Journal of Orthodontics	Sukhia et al.	2012
Validity of different dental age estimation methods in Pakistani orthodontic patients	Australian Journal of Forensic Sciences	Khoja et al.	2014
Aspartic acid racemization with correlation to age: a forensic perspective	Journal of the College of Physicians and Surgeons – Pakistan	Hassan et al.	2017
Age estimation using canine pulp volumes in adults: a CBCT image analysis	International Journal of Legal Medicine	Kazmi et al.	2019
Radiographic employment of mandibular third-molar mineralisation to estimate chronological age in a population of Peshawar, Pakistan	<i>Journal of Pakistan Dental Association</i>	Tariq et al	2021
Relationship between chronological age and dental age using third molar calcification in the Pakistani Population	Journal of the College of Physicians and Surgeons – Pakistan	Bashir et al.	2023
Forensic age estimation from lower third molar maturity index	Pakistan Armed Forces Medical Journal	Ullah et al.	2023
Dental age estimation methods tested in a sample of the Pakistani Population: cross-sectional study	Oral	Khan et al.	2023

Table 2. Detail of the eligible studies

3. RESULTS

Selection of Studies

The initial search found 1771 studies (including the “grey literature”). The studies included from PubMed were 1405, LILACS = 3, ScienceDirect = 359, OATD = 4. After the exclusion of duplicates (n = 4), a total of 1767 studies remained. Title reading led to the exclusion of 1503 studies. Abstract reading led to the exclusion of 247 studies based on the partial application of the eligibility criteria. A total of 17 studies remained for full text reading. Out of the 17 studies, seven were excluded because of their study design and three were not related to the studied topic. One study was added by expert opinion, and a total of eight articles were included in this scoping review (Figure 1).

Characteristics of the studies

The eligible studies were published between 2012 and 2023 and were conducted in various regions of Pakistan (Table 2). Demirjian’s staging technique was the most studied (n = 4).[17,18,21,22] Other methods based on the staging of dental mineralization were Nolla’s (n = 1), Willems’ (n = 1) and Köhler’s (n = 1). Other methods included metric analyses (e.g. Kvaal’s and Cameriere’s methods), volumetric analysis and aspartic acid racemization (Table 3). The sample size of all the included articles was 3,144, in which the highest sample (n = 882) size was observed in the study by Sukhia et al. [28] The age range of the studies included was between 7 to 70 years.

In a study conducted by Sukhia et al. in southern Pakistani population, applicability of dental age assessment by Demirjian’s method was tested. The study also formulated a separate dental age table because the results stated significant over-estimation in the 7 year and 11–14 year age groups in males and in all age groups among females. The mean difference ranged from -1.17 to -0.12 for the male sample and from -1.14 to -0.02 for the female sample according to Demirjian method, while with a new dental age table, the mean difference dropped to -0.007 years in males and to 0.012 years for females.[28]

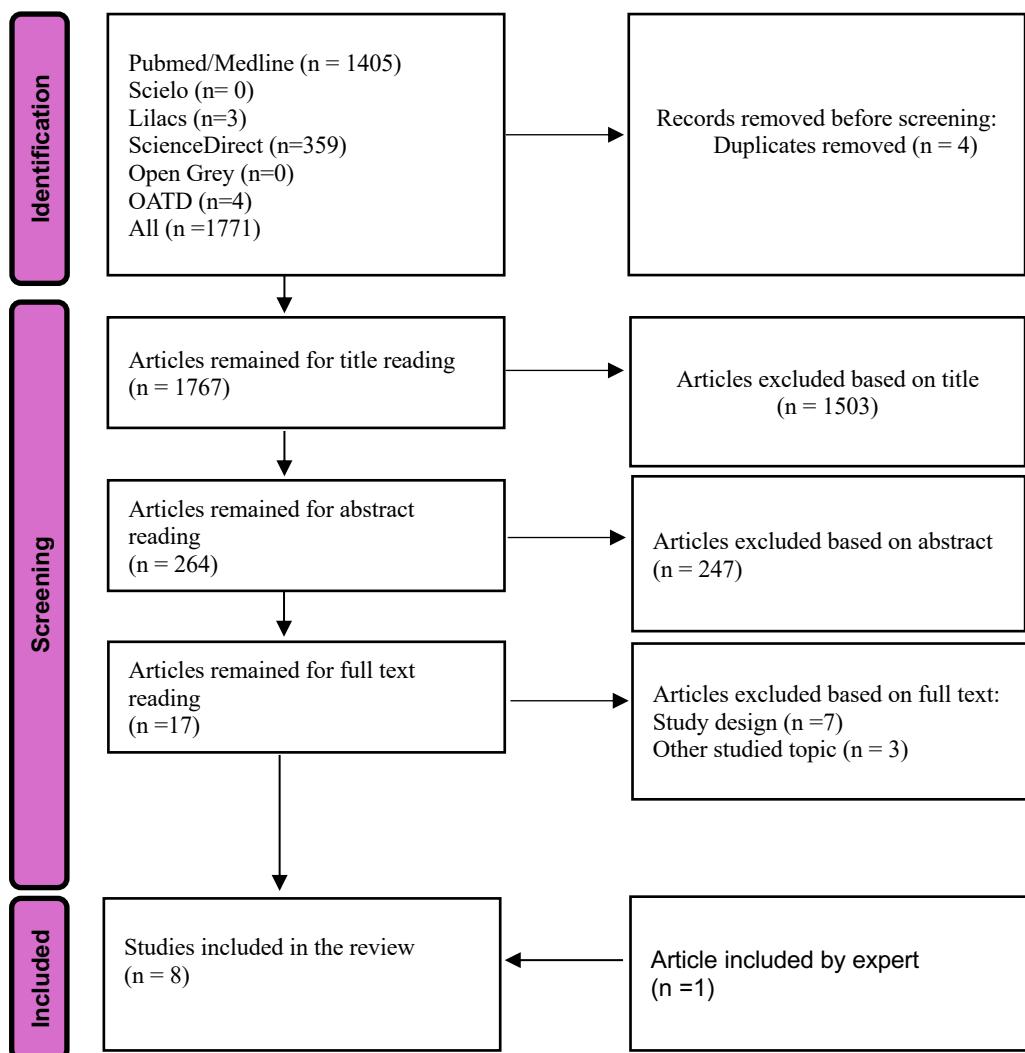
According to the study performed by Khoja et al. on Pakistani orthodontic patients in Karachi, to evaluate the validity of Demirjian’s, Nolla’s and Willems’ methods it was found that chronological age is strongly correlated with dental age in males and females with any of the methods used. The studies stated the following differences in chronological age and dental age in the methods used: Nolla’s: -1.00 ± 1.54 years for males and 0.21 ± 1.64 years for females; Demirjian’s: 0.32 ± 1.17 and 0.38 ± 1.33 years for males and females, respectively; and Willems’: 0.31 ± 1.09 years for males and 0.29 ± 0.48 years for females. Dental age correlated better with chronological age and there was less overestimation found using Pakistani tables proposed by Sukhia et al. compared with original tables based on French-Canadian standards. The most valid method for dental age estimation in Pakistani population was found to be Willems’ method.[29]

Referring to the study by Hassan et al. performed in Karachi, Pakistan, using aspartic acid racemization in human dentin method to calculate age, the mean dental age (38.44 ± 13.22 years) was not significantly different from the mean calibrated age (37.52 ± 12.36 years).[30]

In order to assess the relationship between chronological age and pulp volumes from a homogenous age distribution, a study was conducted by Kazmi et al. in 2019 on CBCT using canine pulp volumes. The study also evaluated the effect of sex as predictor in age estimation. The findings suggested that mandibular canine pulp volumes have stronger relationship with chronological age as compared with maxillary canine pulp volume. It also indicated that sex as a predictor improved the age estimation.[31]

In the study by Tariq et al., a correlation between Chronological age and mandibular third molar development by using Demirjian's method was assessed and it was found that there were no statistically significant differences between males and females.[32]

Figure.1: PRISMA flowchart showing the research steps of identification, screening and inclusion of studies



Bashir et al. assessed the relationship between dental age and chronological age by using third molar calcification stages according to the 10-stage system proposed by Kohler et al. and found a relationship between dental development and age, and observed proper applicability for female and male Pakistani individuals.[33]

Referring to the study by Ullah et al. to estimate the age from mandibular third molar maturation stages using Demirjian's staging technique, the authors found a mean age of 16.76 ± 2.19 years, ranging from 14 to 24 years, proving it to be a reliable method for age estimation in the Pakistani population.[34]

In the study by Khan et al. in Islamabad, Bang & Ramm, Lamendin, Cameriere and Kvaal methods were applied for dental age estimation from teeth extracted from adults. Bang & Ramm was found to be most accurate for the Pakistani population, however, due to limited and non-homogenous data, further studies were suggested to verify the validity of Lamendin's, Cameriere's and Kvaal's methods.[35]

Authors, year	Sample (n)	M	F	Age	DAE Method	Population	Ethics
Sukhia et al. [28]	882	427	455	7-14.99	Demirjian's (1973)	Dental OPGs of Pakistani patients with no prior orthodontic treatment history	n/r
Khoja et al. [29]	403	176	227	8-16.9	Demirjian's (1973), Nolla's (1960), Willems' (2001)	Dental OPGs of Pakistani orthodontic patients	n/r
Hassan et al. [30]	100	62	38	12-70	Aspartic acid Racemization	Teeth obtained from patients at the orthodontics department including incisors, canines, premolars and molars.	Approval reported.
Kazmi et al. [31]	717	349	368	15-65	CBCT based pulp chamber volumetric analysis	CBCT images from a database of the Advance Digital Imaging Centre Lahore Pakistan	Approval reported.
Tariq et al. [32]	470	215	255	13-26	Third molars assessed with Demirjian's (1973) staging and age obtained from a modified calculation.	Dental OPGs of Pakistani orthodontic patients	Approval reported.
Bashir et al. [33]	385	121	264	12-28	Third molars assessed with Kohler's (1994) staging and age obtained from a modified calculation.	Dental OPGs of Pakistani patients at Dow University of Health Sciences	Approval reported.
Ullah I et al. [34]	150	n/r	n/r	14-24	Third molars assessed with Demirjian's (1973) staging and age obtained from a modified calculation.	Dental OPGs of Pakistani patients.	Approval reported.
Khan A et al. [35]	37	16	21	23-68	Bang & Ramm's (1970), Lamendin's (1992), Cameriere's (2004), Kvaal's (1995)	Teeth from Pakistani patients who visited OMFS department of the Islamic International dental Hospital, Islamabad.	Approval reported.

Table 3. Main characteristics of the eligible studies. n/r: not reported; M: males; F: females; CBCT: Cone Beam Computed Tomography; Age reported in years; OPG: orthopantomogram; OMFS: Oral and Maxillofacial Surgery.

4. DISCUSSION

Like any other country, Pakistan is not free from armed conflicts, natural disasters, and other situations in which human identification becomes essential and dental age estimation plays a supporting role. Numerous studies have been conducted worldwide to develop and validate dental age estimation methods, yet only a limited number have focused on the Pakistani population. This gap reduces the applicability of international reference standards in local forensic and clinical settings. Accordingly, this scoping review aims to map and analyze the existing literature on dental age estimation methods applied in Pakistan, highlighting the current evidence and identifying optimal justifications to guide future research.

The main outcome of the present study was the evident diversity of methodological approaches for dental age estimation research conducted in Pakistan since 2012. Studies not only addressed traditional dental age estimation methods, such as the

bidimensional radiographic assessment of stages of crown and root development of the permanent teeth and third molars, but also performed analysis of volumetric morphological features, and invasive biochemical or macroscopic techniques for (the latter being destructive and non-destructive). Amongst all, the most frequently applied approach was the staging system proposed by Demirjian et al. (1973) [6]. This is an eight-stage classification system originally based on French-Canadian standards that has been widely applied in dental age estimation studies in different populations [36, 37]. Controversy exists regarding the overall reliability of this method in different populations. While authors have suggested an overall overestimation of the method (through a systematic review), the differences observed between chronological and estimated ages have been considered small enough to endorse the method as applicable irrespective of ethnicity [36]. Other authors (with a different systematic review) confirmed the overestimations observed following the application of the Demirjian's method, but highlighted lesser accuracy and reliability compared to other dental age estimation methods [37]. However, it must be noticed that current applications in the Pakistani population have used the method as originally proposed, while others used only Demirjian's staging technique followed by varied approaches to calculate the estimated age. Although this method was originally tested on the French-Canadian population, studies have been published to formulate new reference tables or adaptations to target populations. In the present scoping review, authors have endorsed the method for age estimation in the Pakistani population, but evidence remains scarce. Oppositely to what was originally proposed in Demirjian's study, some of the studies conducted in Pakistan have used the staging system for third molar assessment. While adaptation may be useful, this strategy may not be the best for third molars, since the original staging system proposed by Demirjian has only eight stages of crown-root formation. Considering the fact that third molar development is normally assessed when the judicial interest behind dental age estimation is within the interval between 15 and 22 years, a staging system that included a more detailed description of tooth formation could be preferred. Examples include Moorrees' and Köhler's staging systems.

In late adolescence, the permanent teeth, except third molars, have completed their development. As consequence, a decrease of dental age estimation accuracy is expected, since less developmental parameters are available. Moreover, third molars frequently present anatomic variations, impaction and agenesis. [38] The assessment of these teeth is of particular importance in forensic practice, since these teeth are normally the last to develop and are therefore central to expert evaluations when the age of interest is 18 years—the threshold of civil and criminal majority in most countries, including Pakistan. In such contexts, the proper selection of methods and the availability of reference studies developed specifically with Pakistani datasets are fundamental resources for producing reliable forensic odontologists' reports. Despite the fact that Pakistan may not always be listed among the main countries of origin of asylum seekers documented in forensic epidemiological studies in Europe [39], it remains a nation with a very large population and considerable migratory flows, both legal and irregular. This demographic reality underscores the importance of developing population-specific standards that can be applied not only within the country but also abroad, whenever Pakistani nationals are involved in asylum or migration procedures. Without this scientific foundation, the risks of error increase considerably. Suboptimal practices based on limited or non-representative literature can lead to serious consequences, such as the misclassification of adults as minors or, even more critically, the classification of minors as adults. The latter error is especially grave, as it may result in the deprivation of civil rights, denial of protection measures, or, in criminal proceedings, the imposition of sentences and convictions wrongfully grounded on flawed forensic evidence. From a human rights perspective, these misclassifications are not only technical shortcomings but ethical breaches with profound social and legal implications. Strengthening research on third molar development in the Pakistani population is therefore an urgent priority to ensure both scientific accuracy and the protection of individual rights in forensic and judicial processes.

Overall, the body of research on dental age estimation in Pakistan demonstrates significant heterogeneity in methodology, reporting, and study design, which limits the strength, applicability and (especially) generalization of the current evidence. Existing studies have explored a wide spectrum of techniques, ranging from conventional two-dimensional radiographic assessments of permanent teeth and third molars, volumetric analyses using CBCT scans, and even invasive or biochemical approaches such as aspartic acid racemization and macroscopic analyses of teeth *ex vivo*. While this diversity indicates an active interest of the Pakistani academic community in the field, it also reflects the need for more standardized practices. More specifically, it is worth noticing that some methods have been applied with modifications (not as originally proposed)—most notably, the frequent adaptation of Demirjian's staging system for third molar estimation. Such variations hinder comparability across studies and complicate the establishment of reliable population-specific reference standards. Another persistent challenge is the imbalance and inadequate reporting of sample characteristics. Several studies relied on relatively small or convenience samples, often with uneven distributions across sex and age groups, or with incomplete documentation of these variables (especially age distributions per age intervals). These shortcomings not only reduce the statistical power of findings but also limit the representativeness of the results for the broader Pakistani population. Furthermore, important aspects of scientific rigor are inconsistently applied: adherence to international reporting frameworks such as the STROBE statement is null, and inter- and intra-observer agreement tests—which are indispensable for validating observer-dependent methods like tooth stage classification—are frequently absent.

For future research, several steps are essential to strengthen the evidence base. Studies should be designed with larger, systematically selected samples that adequately represent both sexes and cover relevant age intervals, thereby ensuring greater generalizability, and rigorous adherence to standardized protocols, without unnecessary modifications, will be crucial for comparability across national and international contexts. Researchers should also commit to transparent and structured reporting in line with guidelines such as STROBE, while consistently incorporating reliability assessments of observer performance. Beyond improving individual study quality, collaborative, multicenter projects across different regions of

Pakistan could generate harmonized datasets that allow for robust cross-validation of methods. Such initiatives would make it possible to have a better evaluation of the methods' relative accuracy and practicality in the country.

5. CONCLUSION

The diversity of approaches applied in studies from Pakistan reflects the academic community's growing interest in dental age estimation; however, the current evidence is constrained by important methodological limitations. Variability in study design, sample representativeness, and adherence to standardized protocols restricts comparability and reduces the reliability of findings. Future investigations must address these issues to establish robust, population-specific reference standards and strengthen the field's forensic and clinical applicability.

Conflict of Interest

There was no conflict of interest.

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Authors Contribution

Conceptualization: Ademir Franco, Amber Khan. Methodology: Ademir Franco. Formal Analysis: Ademir Franco. Funding Acquisition: Not applicable. Data Curation: Amber Khan, Bakhtawar Yaqoob. Original Draft Writing: Amber Khan. Supervision and Editing: Ademir Franco. Administration: Ademir Franco, Amber Khan

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Reference

- [1] Harvey W. *Dental identification and forensic odontology*. London, UK: Henry Kimpton Publishers; 1976.
- [2] Keiser-Nielsen S. *Forensic odontology*. *Int Dent J* 1968;18:668-83.
- [3] International Criminal Police Organization. *Disaster victim identification guide*. Lyon, FR: INTERPOL; 2023.
- [4] Senn DR, Weems RA. *Manual of forensic odontology*. 5th ed. Boca Raton, FL: CRC Press; 2013.
- [5] Willems G, Van Olmen A, Spiessens B, Carels C. Dental age estimation in Belgian children: Demirjian's technique revisited. *J Forensic Sci* 2001;46(4):893-5.
- [6] Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. *Hum Biol* 1973;45(2):211-27.
- [7] Nolla CM. The development of permanent teeth. *J Dent Child* 1960;27:254-66.
- [8] Cameriere R, Ferrante L, Cingolani M. Variations in pulp/tooth area ratio as an indicator of age: a preliminary study. *J Forensic Sci* 2004;49(2):317-9.
- [9] D'Albuquerque LOS, Moreira DD, Boedi RM, Franco A. Morphological dental age estimation of adults using the radiographic canine pulp/tooth area ratio. *Morphologie* 2024;108(363):100903.
- [10] Gustafson G. Age determination on teeth. *J Am Dent Assoc* 1950;41(1):45-54.
- [11] Divakar KP. *Forensic Odontology: The New Dimension in Dental Analysis*. International journal of biomedical science : IJBS. 2017;13(1):1-5.
- [12] Shah P, Velani PR, Lakade L, Dukle S. Teeth in forensics: A review. *Indian Journal of Dental Research*. 2019;30(2):291-9.
- [13] Adserias Garriga J. Evolution of methods and state-of-the-art in dental age estimation. 2019. p. 77-87.

[14] Refn MR, Kampmann M-L, Morling N, Tfelt-Hansen J, Børsting C, Pereira V. Prediction of chronological age and its applications in forensic casework: methods, current practices, and future perspectives. *Forensic Sciences Research*. 2023;8(2):85-97.

[15] De Donno A, Angrisani C, Mele F, Introna F, Santoro V. Dental age estimation: Demirjian's versus the other methods in different populations. A literature review. *Medicine, Science and the Law*. 2021;61(1_suppl):125-9.

[16] Sengupta N, Sarode SC, Sarode GS, Gadbaile AR, Gondivkar S, Patil S, et al. Analysis of 100 most cited articles on forensic odontology. *The Saudi dental journal*. 2020;32(7):321-9.

[17] Han M-q, Jia S-x, Wang C-X, Chu G, Chen T, Zhou H, et al. Accuracy of the Demirjian, Willems and Nolla methods for dental age estimation in a northern Chinese population. *Archives of Oral Biology*. 2020;118:104875.

[18] Kurniawan A, Chusida An, Atika N, Gianosa TK, Solikhin MD, Margaretha MS, et al. The applicable dental age estimation methods for children and adolescents in Indonesia. *International journal of dentistry*. 2022;2022(1):6761476.

[19] Verma M, Verma N, Sharma R, Sharma A. Dental age estimation methods in adult dentitions: An overview. *Journal of forensic dental sciences*. 2019;11(2):57-63.

[20] De las Heras SM. Chapter 9 - Dental age estimation in adults. In: Adserias-Garriga J, editor. *Age Estimation*: Academic Press; 2019. p. 125-42.

[21] Sharma N, Dhillon S. Identification through dental age estimation in skeletal remains of a child. *Journal of Forensic Dental Sciences*. 2019;11(1):48-50.

[22] Solheim T, Sundnes PK. Dental age estimation of Norwegian adults—a comparison of different methods. *Forensic science international*. 1980;16(1):7-17.

[23] Lamendin H, Baccino E, Humbert JF, Tavernier JC, Nossintchouk R, Zerilli A. A simple technique for age estimation in adult corpses: the two criteria dental method. *Journal of forensic sciences*. 1992;37(5):1373-9.

[24] Suciyanie IM, Gultom FP, Hidayat AN, Suhartono AW, Yuniautti M, Auerkari EI. Accuracy of forensic age estimation using cementum annulation and dentin translucency in adult: a systematic review and meta-analysis. *International Journal of Legal Medicine*. 2022 Sep;136(5):1443-55.

[25] Aslam RW, Shu H, Yaseen A. Monitoring the population change and urban growth of four major Pakistan cities through spatial analysis of open source data. *Annals of GIS*. 2023;29(3):355-67.

[26] Baig MZ, Siddiqi KM, Jabeen N, Israr M, Ehsan MT, Rahman F. Awareness and compliance about forensic dentistry among dental professionals of twin cities of Rawalpindi-Islamabad: a questionnaire-based study. *Pak Oral Dent J* 2014;34(2):277-80.

[27] Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. *Ann Intern Med*. 2018;169(7):467-73.

[28] Sukhia RH, Fida M, Azam SI. Dental age table for a sample of Pakistani children. *Eur J Orthod*. 2012 Feb;34(1):77-82.

[29] Khoja A, Fida M, Shaikh A. Validity of different dental age estimation methods in Pakistani orthodontic patients. *Australian Journal of Forensic Sciences*. 2015 Jul 3;47(3):283-292.

[30] Hassan Q, Rakha A, Bashir MZ. Aspartic Acid Racemization with Correlation to Age: A Forensic Perspective. *Journal of the College of Physicians and Surgeons--Pakistan : JCPSP*. 2017;27(5):283-7

[31] Kazmi S, Zaidi SJA, Reesu GV, Shepherd S. Dental age estimation using the Kvaal method—an evaluation of length and width ratios: a systematic review. *Forensic Science, Medicine and Pathology*. 2024;20(1):239-48.

[32] Tariq Q, Tareen MA, Uddin I, Hussain U. Radiographic Employment of Mandibular Third-Molar Mineralisation to Estimate Chronological Age in a Population of Peshawar, Pakistan. *Journal of The Pakistan Dental Association*. 2021 Jan 1;30(1).

[33] Bashir MB, Zaidi SJA, Anwar M, Ruaaz R, Baqai HS, Baig QA. Relationship between Chronological Age and Dental Age Using Third Molar Calcification in the Pakistani Population. *Journal of the College of Physicians and Surgeons--Pakistan : JCPSP*. 2023;33(1):15.

[34] Ullah I, Khurshid H, Ahmed I, Rehman R, Atiq S. Forensic Age Estimation from Lower Third Molar Maturity Index. *Pakistan Armed Forces Medical Journal*. 2023 Apr 30;73(2):531.

- [35] Khan A, Manica S, Franco A. Dental Age Estimation Methods Tested in a Sample of the Pakistani Population: Cross-Sectional Study. *Oral*. 2023 Nov 20;3(4):511-25.
- [36] Hostiuc S, Edison SE, Diaconescu I, Negoi I, Isaila OM. Accuracy of the Demirjian's method for assessing the age in children, from 1973 to 2020: a meta-analysis. *Leg Med (Tokyo)* 2021;52:101901.
- [37] Vistro AA, Farooqui SS, Saeed MH, Maqbool A, Ghauri MQK, Dherwani V, et al. Evaluating the accuracy and reliability of the Demirjian method for dental age assessment: a systematic review. *Pak J Health Sci* 2024;5(12):363-71.
- [38] Bagherpour A, Anbiaee N, Partovi P, Golestani S, Afzalinasab S. Dental age assessment of young Iranian adults using third molars: A multivariate regression study. *Journal of forensic and legal medicine*. 2012;19(7):407-12.
- [39] Thicot F, Egger C, Castiglioni C, Magnin V, Boudabbous S, Angelakopoulos N, et al. Forensic age estimation at the University Center of Legal Medicine Lausanne-Geneva: a retrospective study over 12 years. *Int J Legal Med* 2024;138:1881-9.