REVIEW DERLEME

DOI: 10.5336/forensic.2025-113806

Forensic Dental Age Estimation in Turkish Children Using Panoramic Radiographs: Systematic Review

Panoramik Radyograflar Kullanılarak Türk Çocuklarında Adli Diş Yaşı Tahmini: Sistematik Derleme

Berkant SEZER[a]

[a]Çanakkale Onsekiz Mart University Faculty of Dentistry, Department of Pediatric Dentistry, Çanakkale, Türkiye

ABSTRACT Dental age estimation is an essential element of forensic investigations when documentary age evidence is missing, incomplete, or unreliable. This systematic review synthesises research on dental age estimation in Turkish children using panoramic radiographs, following PRISMA methodology. Six electronic databases were searched for studies published between January 2010-August 2025. Thirty retrospective studies met inclusion criteria, comprising participants aged 2.2-18 years with sample sizes of 150-1,878. Commonly applied techniques were Willems, Cameriere, Nolla, and Demirjian, alongside regional adaptations including Cameriere, Blenkin-Evans, Bedek, Haavikko, and the London Atlas. Reported accuracy varied by geographic region, sex, and age group. Willems and Cameriere-based approaches frequently achieved closer estimates to chronological age, yet no single method consistently outperformed others across all Turkish subpopulations. Considerable methodological heterogeneity and regional variation underscore the need for population-specific calibration and well-designed, prospective multicentre validation studies. From a forensic standpoint, selecting a validated, population-appropriate method is critical for legal decisions involving age thresholds such as criminal responsibility and immigration status. Combining complementary methods may reduce systematic bias but increases procedural complexity and resource demands. This review provides the first comprehensive synthesis of panoramic radiograph-based forensic dental age estimation in Turkish children, identifies gaps in geographic coverage and study design, and recommends targeted research to develop standardized, population-specific protocols that enhance accuracy, applicability, and judicial defensibility of age assessments. Such consensus-driven standards would also aid training, accreditation, inter-laboratory comparison, and the translation of research into forensic casework and policy.

Keywords: Dental age estimation; forensic dentistry; forensic odontology; forensic sciences

ÖZET Diş yaşı tahmini, belgeye dayalı yaş bilgisinin bulunmadığı, eksik ya da güvenilir olmadığı durumlarda adli soruşturmaların temel unsurlarından biridir. Bu sistematik derleme, Türk çocuklarında panoramik radyograflere dayalı adli diş yaşı tahmini araştırmalarını sentezlemektedir. PRISMA metodolojisi izlenerek, Ocak 2010-Ağustos 2025 tarihleri arasında yayımlanan çalışmaları belirlemek amacıyla altı elektronik veri tabanı taranmıştır. Dahil edilme kriterlerini karşılayan 30 retrospektif çalışma incelenmiş olup, bu çalışmalar 2,2–18 yaş aralığındaki ve örneklem büyüklükleri 150–1.878 arasında değişen katılımcıları kapsamaktadır. En sık kullanılan yöntemler, Willems, Cameriere, Nolla ve Demirjian olup, Cameriere, Blenkin-Evans, Bedek, Haavikko ve Londra Atlası gibi uyarlamalar da değerlendirilmiştir. Bulgular, doğruluğun coğrafi bölge, cinsiyet ve yaş grubuna göre değiştiğini göstermektedir. Willems ve Cameriere temelli yöntemler sıklıkla kronolojik yaşa daha yakın sonuçlar verse de hiçbir yöntem, tüm Türk alt popülasyonlarında sürekli üstünlük sağlamamıştır. Belirgin yöntemsel heterojenlik ve bölgesel farklılıklar, popülasyona özgü kalibrasyonların gerekliliğini ve iyi tasarlanmış, ileriye dönük çok merkezli doğrulama çalışmalarına duyulan ihtiyacı ortaya koymaktadır. Adli uygulamalarda, hedef popülasyona uygun ve doğrulanmış yöntemlerin seçilmesi, cezai sorumluluk ve göçmenlik gibi yaş eşiği ile ilgili hukuki kararlar açısından kritik önem taşımaktadır. Farklı yöntemlerin birlikte kullanımı sistematik yanlılığı azaltabilir; ancak işlem karmaşıklığını ve kaynak ihtiyacını artırır. Bu derleme, Türk çocuklarında panoramik radyografilere dayalı adli diş yaşı tahmini alanındaki literatürün ilk kapsamlı sentezini sunmakta, coğrafi kapsam ve çalışma tasarımına ilişkin mevcut boşlukları ortaya koymakta ve popülasyona özgü standartlaştırılmış protokollerin geliştirilmesinin yaş tahminlerinin doğruluğunu, uygulanabilirliğini ve hukuki açıdan savunulabilirliğini artırabileceğini göstermektedir. Ayrıca uzlaşıya dayalı standartların oluşturulması; eğitim, akreditasyon, laboratuvarlar arası karşılaştırma ve araştırma bulgularının adli vaka uygulamalarına aktarımını kolaylaştıracaktır.

Anahtar Kelimeler: Diş yaşı tahmini; adli diş hekimliği; adli odontoloji; adli bilimler

TO CITE THIS ARTICLE:
Sezer B. Forensic dental age estimation in Turkish children using panoramic radiographs: Systematic review. Turkiye Klinikleri J Foren Sci Leg Med. 2026;23(2):182-95.

Correspondence: Berkant SEZER
Çanakkale Onsekiz Mart University Faculty of Dentistry, Department of Pediatric Dentistry, Çanakkale, Türkiye
E-mail: dt.berkantsezer@gmail.com

Peer review under responsibility of Turkiye Klinikleri Journal of Forensic Medicine and Forensic Sciences.

Received: 10 Aug 2025 ***Received in revised form:*** 20 Nov 2025 ***Accepted:*** 29 Dec 2025 ***Available online:*** 15 Jan 2026

2619-9459 / Copyright © 2026 by Türkiye Klinikleri. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Forensic sciences encompass a broad spectrum of disciplines that apply scientific principles and techniques to matters of law and justice.[1] Among these disciplines, forensic odontology is a specialized branch that deals with the examination, evaluation, and presentation of dental evidence in legal proceedings.[2,3] Forensic odontology encompasses a variety of tasks, including human identification, bite mark analysis, dental age estimation, and the examination of oral injuries in cases of abuse or trauma.[4,5] By integrating dental science with legal requirements, forensic odontology plays a pivotal role in both civil and criminal investigations.[2-5]

The significance of forensic odontology lies in its capacity to provide reliable and often unique forms of evidence that may be critical when other identification methods are unavailable or inconclusive. In cases involving mass disasters, unidentified human remains, child abuse, and criminal assaults, dental evidence can often survive extreme conditions, making it an indispensable resource.[6-8] Forensic odontologists contribute not only to victim identification but also to the resolution of disputed cases concerning age, sex, and personal identity. Their work bridges the gap between clinical dentistry and forensic investigation, providing courts and law enforcement agencies with scientifically grounded findings that can withstand judicial scrutiny.[9,10]

One of the key responsibilities within forensic odontology is forensic age estimation, which involves determining the chronological age of an individual when documentary evidence is absent or questionable.[11,12] Age estimation methods vary according to the developmental stage of the individual. In children and adolescents, the assessment is typically based on growth and maturation indicators, such as skeletal development, dental development, and secondary sexual characteristics.[13,14] Common approaches include the evaluation of hand-wrist radiographs, clavicular ossification, and dental maturity.[14-16] Dental age estimation is often preferred for its high accuracy during childhood and adolescence, owing to the predictable sequence of tooth development and mineralization.[14,17]

Forensic dental age estimation methods are based on the analysis of tooth formation and eruption stages, assessed through clinical examination, radiographic imaging, or advanced imaging techniques.[12-15,17,18] Among these, panoramic radiography is widely utilized due to its ability to provide a comprehensive view of all teeth and developing tooth germs in a single image.[19] Established techniques such as the Demirjian, Nolla, Willems, and Cameriere methods rely on evaluating specific developmental stages of teeth on panoramic radiographs.[20-23] Other methods, including cone-beam computed tomography and digital image analysis, are also applied in certain contexts; however, their use is often limited in forensic casework due to cost, accessibility, and radiation considerations.[18] In the present review, the focus is limited to studies employing panoramic radiographs for dental age estimation in Turkish children for forensic purposes.

Despite the growing number of studies on dental age estimation, there is currently no comprehensive synthesis of research focusing exclusively on Turkish children and panoramic radiograph-based forensic methods. Understanding the accuracy, applicability, and limitations of these methods in a specific population is essential, as dental development patterns may vary across ethnic and geographical groups. This review aims to map the existing literature on forensic dental age estimation methods used in Turkish children based on panoramic radiographs, identify the range of methods applied, and summarize the reported outcomes. By doing so, the review intends to fill a gap in the literature, provide guidance for forensic practitioners, and inform future research and standardization efforts in this field.

MATERIAL AND METHODS

This review was conducted in accordance with the PRISMA guidelines. The review process was guided by the Population-Concept-Context (PCC) framework recommended by the Joanna Briggs Institute for reviews.

PCC framework:

- Population (P): Turkish children (0-18 years).
- Concept (C): Dental age estimation methods.
- Context (C): Forensic purposes, using panoramic radiographs.

ELIGIBILITY CRITERIA

The review included studies published between January 2010-August 2025, written in English, and available as full-text articles. Eligible studies were original research conducted on Turkish children aged 0-18 years, in which dental age estimation methods were applied for forensic purposes using panoramic radiographs as the primary imaging modality. Studies were excluded if they were review articles, case reports, editorials, conference abstracts, or letters; if they did not involve Turkish children; if they were not conducted for forensic purposes; if they employed imaging techniques other than panoramic radiography; or if the full text was not accessible.

INFORMATION SOURCES AND SEARCH STRATEGY

A comprehensive literature search was carried out in PubMed (National Library of Medicine, Bethesda, MD, USA), Web of Science (Clarivate, London, UK), Scopus (Elsevier, Amsterdam, The Netherlands), ScienceDirect (Elsevier, Amsterdam, The Netherlands), and Google Scholar (Google LLC, Mountain View, CA, USA) databases. The search covered literature published from January 2010 to August 2025. The following keywords and their combinations were used: "dental age estimation", "dental age assessment", "chronological age estimation", "tooth development", "Turkish children", "children in Turkey", "children in Türkiye", "Turkish population", "forensic", "forensic odontology", "forensic dentistry", "panoramic radiograph", "orthopantomograph", and "OPG". Boolean operators ("AND", "OR") were applied as appropriate, and search terms were adapted to the syntax of each database. The full search strings for each database, along with applied date ranges, are presented in Table 1. Reference lists of included studies were also manually screened to identify any additional eligible publications.

SELECTION PROCESS

Two reviewers independently screened the titles and abstracts of all retrieved records to assess eligibility. Full texts of potentially relevant articles were

TABLE 1: Full search strings used in each database (January 2010-August 2025)

Database	Date range	Search string
PubMed	Jan 2010-Aug 2025	("dental age estimation" OR "dental age assessment" OR "chronological age estimation" OR "tooth development") AND ("Turkish children" OR "children in Turkey" OR "children in Türkiye" OR "Turkish population") AND ("forensic" OR "forensic odontology" OR "forensic dentistry") AND ("panoramic radiograph" OR "orthopantomograph" OR "OPG")
Web of Science	Jan 2010-Aug 2025	TS =("dental age estimation" OR "dental age assessment" OR "chronological age estimation" OR "tooth development") AND TS=("Turkish children" OR "children in Turkey" OR "children in Türkiye" OR "Turkish population") AND TS=("forensic" OR "forensic odontology" OR "forensic dentistry") AND TS=("panoramic radiograph" OR "orthopantomograph" OR "OPG")
Scopus	Jan 2010-Aug 2025	TITLE-ABS-KEY ("dental age estimation" OR "dental age assessment" OR "chronological age estimation" OR "tooth development") AND TITLE-ABS-KEY ("Turkish children" OR "children in Turkey" OR "children in Türkiye" OR "Turkish population") AND TITLE-ABS-KEY ("forensic" OR "forensic odontology" OR "forensic dentistry") AND TITLE-ABS-KEY ("panoramic radiograph" OR "orthopantomograph" OR "OPG")
ScienceDirect	Jan 2010-Aug 2025	("dental age estimation" OR "dental age assessment" OR "chronological age estimation" OR "tooth development") AND ("Turkish children" OR "children in Turkey" OR "children in Türkiye" OR "Turkish population") AND ("forensic" OR "forensic odontology" OR "forensic dentistry") AND ("panoramic radiograph" OR "orthopantomograph" OR "OPG")
Google Scholar	Jan 2010-Aug 2025	All in title: ("dental age estimation" OR "dental age assessment" OR "chronological age estimation" OR "tooth development") AND ("Turkish children" OR "children in Turkey" OR "children in Türkiye" OR "Turkish population") AND ("forensic" OR "forensic odontology" OR "forensic dentistry") AND ("panoramic radiograph" OR "orthopantomograph" OR "OPG")

TS: Topic Search

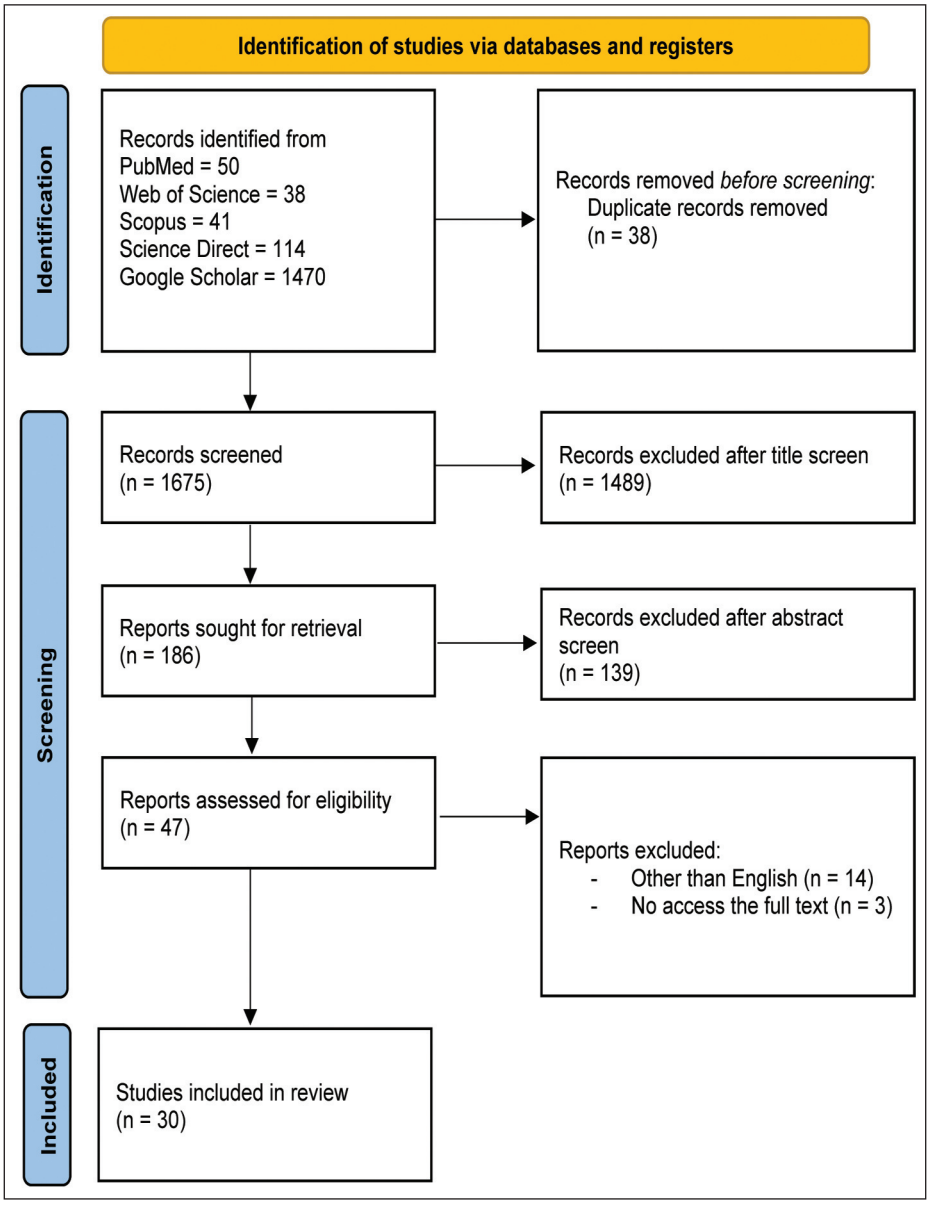


FIGURE 1: Flowchart of the study selection process according to the PRISMA guidelines

then reviewed in detail. Any discrepancies were resolved through discussion or, when necessary, by consulting a third reviewer. The study selection process is illustrated in Figure 1 (PRISMA flow diagram).

DATA CHARTING AND SYNTHESIS

From each included study, the following data were extracted: author(s), year of publication, study design, sample size, age range, sex distribution, geographical region/city, dental age estimation method(s) used, main findings and reported accuracy. Data extraction was performed using a standardized form developed by the review team. In the included studies, dental age estimation was primarily based on the evaluation of permanent teeth, most frequently canines, premolars, and molars. The specific criteria varied according to the applied method. Demirjian's method assessed 8 developmental stages of crown and root formation, while Nolla's method employed 10 calcification stages. Cameriere's approach measured the width of open apices and calculated ratios relative to tooth length,

whereas Willems' method adapted Demirjian's stages with updated scoring tables. Other techniques, such as Haavikko, Blenkin-Evans, Bedek, and the London Atlas, also relied on tooth-specific developmental or morphological parameters. The results were synthesized descriptively, without statistical pooling.

RESULTS

The database search yielded a total of 1,713 records: 50 from PubMed, 38 from Web of Science, 41 from Scopus, 114 from ScienceDirect, and 1,470 from Google Scholar. After the removal of 38 duplicates, 1,675 records remained for screening. Title screening excluded 1,489 records, leaving 186 abstracts for review. Of these, 139 were excluded primarily because they did not meet the eligibility criteria: many did not involve Turkish children, some used imaging modalities other than panoramic radiographs, and others were not conducted for forensic purposes. The 47 full-text articles retrieved were assessed for eligibility, of which 14 were excluded because they were not in English and 3 due to lack of access to the full text. Ultimately, 30 studies met the inclusion criteria and were incorporated into the review. The study selection process is summarized in Figure 1.

A total of 30 retrospective studies met the inclusion criteria, all conducted on Turkish children aged between 2.2-18 years.[24-53] The sample sizes of the included studies varied considerably, ranging from 150 to 1,878 participants. Both sexes were represented in all studies, with relatively balanced male-to-female ratios. Geographically, the research covered diverse regions of Türkiye, including Eastern, Western, Southern, Northwestern, Northeastern, and Central Anatolia, as well as specific cities such as Ankara, İstanbul, Isparta, Konya, and Karaman.[24-26,28-31,33-38,40,42-48,50-53]

All studies utilized panoramic radiographs as the primary imaging modality for dental age estimation, with methods including Demirjian, Nolla, Willems, Cameriere, Cameriere-European, Haavikko, London Atlas, Bedek, and Blenkin-Evans techniques.[24-53] Several studies compared multiple methods to determine the most accurate for their respective subpopulations. Findings revealed regional differences in method applicability, with many studies emphasizing the need for population-specific standards. In some cases, Willems or Cameriere-based approaches yielded the most accurate results, while in others, methods such as Nolla, Haavikko, or Blenkin-Evans performed better.

The main outcomes reported across studies included the degree of overestimation or underestimation of chronological age, sex-related differences in accuracy, and the influence of geographical or ethnic factors on dental development patterns. The overall body of evidence suggests that while commonly used dental age estimation techniques are applicable to Turkish children, their accuracy varies by region, sex, and age group, highlighting the importance of population-specific calibration. Detailed information on each included study is presented in Table 2.

Although all included studies were retrospective in nature and relied on panoramic radiographs, 2 investigations adopted unique comparative approaches. Cantekin et al. compared children from Central and Eastern Türkiye to assess the influence of climatic differences on dental maturation, reporting that Central Anatolian children were 0.2 to 3.0 years more advanced in dental maturity than their Eastern Anatolian counterparts.[47] Kaygisiz et al. analyzed panoramic radiographs collected over a 30-year period to explore secular trends in dental maturation, concluding that no significant positive secular trend was observed, although sex-specific differences emerged in certain age cohorts.[49] These studies illustrate how dental age estimation research can also provide insights into environmental and temporal influences on dental development.

DISTRIBUTION OF STUDIES BY YEAR AND REGION

The included studies were published between 2010-2025, with an evident increase in research activity after 2015. The highest concentration of publications occurred between 2020-2025, indicating a growing academic interest in forensic dental age estimation in the Turkish pediatric population. Early studies (2010-2014) primarily focused on the applicability of established methods such as Demirjian and Nolla in specific regional populations, while more recent studies have incorporated alternative or modified approaches, including Cameriere-European, Blenkin-Evans, and Bedek methods.

TABLE 2: Author/s, publication year, study design, sample size and age range, sex distributions, geographical region or city, dental age estimation method(s), and main findings and reported accuracy of the 30 articles included in this review

Study number	Author/s	Publication year	Study design	Sample size/age range	Sex distributions	Geographical region/city	Dental age estimation method(s)	Main findings and reported accuracy
1[24]	Kırzıoğlu and Ceyhan	2012	Retrospective	425/7-13	212 males 213 females	Isparta	Nolla-Haavikko-Demirjian methods	Haavikko's method was more accurate in the DA estimation compared to the other methods. All of the 3 methods are not completely suitable for Turkish children and establishment of the population-specific standards is essential and crucial.
2[25]	Altunsoy et al.	2015	Retrospective	685/7-16	340 males 345 females	Western Türkiye	Demirjian method	The applicability of the Demirjian method is not suitable for western Turkish children.
3[26]	Gungor et al.	2015	Retrospective	535/10-18	259 males 276 females	Southern Türkiye	Demirjian method	It is appropriate to use the Demirjian method in southern Turkish children; however, a revision is needed in some age groups.
4[27]	Ozveren and Serindere	2018	Retrospective	766/6-15	380 males 386 females	Thrace Region	Demirjian-Willems methods	Willems method produced more accurate results for almost all age groups of both sexes, and it is better suited for children from the Thrace region of Türkiye, than the Demirjian method.
5[28]	Nur et al.	2012	Retrospective	673/5-16	342 males 331 females	Northeastern Türkiye	Demirjian-Nolla methods	Nolla method was found to be a more accurate method for estimating DA in northeastern Turkish population.
6[29]	Apaydin and Yasar	2018	Retrospective	330/5-16	165 males 165 females	Konya	Demirjian-Willems-Cameriere methods	This study indicated that Willems method determines DA satisfactorily in a Turkish subpopulation.
7[30]	Celikoglu et al.	2010	Retrospective	807/7-15	366 males 441 females	Eastern Türkiye	Demirjian method	The differences between the chronological and DAs were statistically significant in all age groups. The applicability of Demirjian method is not suitable for eastern Turkish population.
8[31]	Erdem et al.	2012	Retrospective	756/5-13	411 males 345 females	Northwestern Türkiye	Demirjian method	The developmental standards used by Demirjian are not suitable for northwestern Turkish children. The methods for determining dental development must have population-specific standards.
9[32]	Kış et al.	2020	Retrospective	1,878/5-15	972 males 906 females	Not mentioned	Willems-Cameriere methods	Both Cameriere's and Willems methods are applicable to the Turkish population. However, researchers should consider that the Cameriere method unbiasedly estimates an individual's age depending on chronological age, while the Willems method overestimates this in all age groups.
10[33]	Koç et al.	2021	Retrospective	919/6-14	460 males 459 females	Eastern Türkiye	London Atlas-Willems-Nolla methods	All 3 methods can be used for DA estimations of Eastern Turkish children. Willems was the most suitable method for this patient sample. However, the London Atlas method may be preferred due to its practicability and comparable accuracy.
11[34]	Gümüşboğa et al.	2024	Retrospective	1,018/5-14	497 males 521 females	Eastern Türkiye	Bedek-Cameriere-European methods	The Cameriere-European method showed higher accuracy in predicting the age of children living in eastern Türkiye compared to the Bedek Models.
12[35]	Sezer and Çarıkçıoğlu	2022	Retrospective	980/6-15	503 males 477 females	Northwestern Türkiye	London Atlas-Haavikko-Cameriere-European methods	Haavikko method is more accurate than the London Atlas and Cameriere-European methods for DA estimation in Turkish children living in northwestern Türkiye.

TABLE 2: Author/s, publication year, study design, sample size and age range, sex distributions, geographical region or city, dental age estimation method(s), and main findings and reported accuracy of the 30 articles included in this review *(devamı)*

Study number	Author/s	Publication year	Study design	Sample size/age range	Sex distributions	Geographical region/city	Dental age estimation method(s)	Main findings and reported accuracy
13[36]	Onat Altan et al.	2016	Retrospective	756/5-15	378 males 378 females	Southern Türkiye	Willems method	The maturity score of Willems' Belgian samples of the DA was applicable to seven groups of the southern Turkish children. The present study reports that Willems' method is more accurate for girls than for boys.
14[37]	Duruk et al.	2022	Retrospective	1,587/3-17	813 males 774 females	Eastern Türkiye	Nolla-Demirjian methods	Nolla's method was more accurate in the chronological age estimation than Demirjian's method in eastern Turkish population.
15[38]	Altan et al.	2017	Retrospective	745/4-16	382 males 363 females	Southern Türkiye	Demirjian-Willems methods	The DA estimation by Willems method was found to be more accurate than Demirjian method in contemporary Turkish pediatric population.
16[39]	Karataş et al.	2012	Retrospective	1,015/5-15	516 males 499 females	Southwestern Türkiye	Demirjian method	Turkish children from the southwest Eastern Anatolia Region are significantly more delayed in dental maturity compared to Demirjian's French-Canadian sample. The applicability of Demirjian data is not suitable for Southwestern of Eastern Anatolia Region of Turkish children.
17[40]	Çarıkçıoğlu and Sezer	2022	Retrospective	1,118/6-16	578 males 540 females	Northwestern Türkiye	Willems-Bedek methods	Seven- and four-teeth models were the most suitable for age estimation, and all models except the one-tooth model were found to be more accurate than the Willems method in northwestern Turkish children.
18[41]	Hato et al.	2022	Retrospective	400/6-14	196 males 204 females	Central Black Sea Region	Nolla-Willems-Cameriere methods	In this study method providing closest estimation for chronological age among children aged 6-14.99 that were examined in Central Black Sea Region, was the Cameriere method in both girls and boys, followed by Nolla method and Willems method, respectively.
19[42]	Celik et al.	2014	Retrospective	932/4-18	488 males 444 females	Southern Türkiye	Demirjian method	Demirjian's standards are not suitable for all age groups of southern Turkish children, a new table is necessary for evaluating this population.
20[43]	Gulsahi et al.	2015	Retrospective	573/8-15	275 males 298 females	Ankara	Cameriere method	This study represents the first investigation of the applicability of the Cameriere's method to a Turkish population.
21[44]	Akkaya et al.	2015	Retrospective	799/2,2-16	387 males 412 females	Ankara	Demirjian-modified Demirjian-Willems methods	Based on the results of this research, it was concluded that Willems method is more suitable than Demirjian methods for DA estimation. Therefore, this method can be used for forensic procedures in Turkish children.
22[45]	Çarıkçıoğlu and Değirmenci	2021	Retrospective	1,024/6-16	619 males/ 585 females	Northwestern Türkiye	Willems-Cameriere-Blenkin-Evans methods	Although Willems and Blenkin-Evans methods both seem satisfactory in age estimation for children at the northwest Anatolia region of Türkiye, Blenkin-Evans method performs slightly better than Cameriere method and it has shown the most accurate results except for the 15 year age group.
23[46]	İzgi and Namdar Pekiner	2023	Retrospective	150/4-14	75 males/ 75 females	İstanbul	Demirjian-Willems methods	The Willems method was shown to be more accurate in determining DA in Turkish children. Further studies on large population groups and diverse ethnicities are required to increase the reliability and repeatability of the results.
24[47]	Cantekin et al.	2014	Comparative and retrospective	944/7-15	494 males 450 females	Central and Eastern Türkiye	Demirjian method	The Central Anatolian children were approximately 0.2 to 3.0 years more advanced in dental maturity than the Eastern Anatolian subjects. The development standards proposed by Demirjian are affected by climatic factors.

TABLE 2: Author/s, publication year, study design, sample size and age range, sex distributions, geographical region or city, dental age estimation method(s), and main findings and reported accuracy of the 30 articles included in this review *(devamı)*

Study number	Author/s	Publication year	Study design	Sample size/age range	Sex distributions	Geographical region/city	Dental age estimation method(s)	Main findings and reported accuracy
25[48]	Şahin and Güleç	2025	Retrospective	616/6-15	295 males 321 females	Karaman	Cameriere-Cameriere-European-Willems-Blenkin-Evans methods	If groups are evaluated separately, the closest results to CA for both sexes were obtained with CM. However, when the mean age difference for all age groups is evaluated by gender, the closest results to all individuals' CA were obtained using the Blenkin-Evans method.
26[49]	Kaygisiz et al.	2016	Comparative and retrospective	757/9-13	385 males 372 females	Not mentioned	Demirjian method	Dental maturation in girls has tended to advance more rapidly than in boys at the same ages over the decades. However, significant differences between girls and boys were only observed among subjects born in the 2000s. Significant positive secular trends in dental maturity were not observed between the 1980s, 1990s, and 2000s. Dental maturation among Turkish children is not affected by a secular trend.
27[50]	Çarıkçıoğlu and Sezer	2025	Retrospective	1,014/6-14	528 males 486 females	Northwestern Türkiye	Nolla-Cameriere-European-Blenkin-Evans methods	The Cameriere-European formula provided the most accurate DA estimation method, followed by the Blenkin-Evans and Nolla methods for Turkish children from the Northwestern Anatolia. However, the observed biases highlight the need for population-specific calibrations.
28[51]	Miloglu et al.	2011	Retrospective	719/6-18	310 males 409 females	Eastern Türkiye	Nolla method	Although the accuracy of this method was suitable for boys, according to our findings, it was not suitable for girls.
29[52]	Ercalikyalcinkaya et al.	2013	Retrospective	1,678/4-16	935 males 743 females	Northwestern Türkiye	Demirjian method	Results show that the mean DAs of the studied group of Turkish children are significantly higher than the chronological ages. Overestimation is notable at the beginning of puberty.
30[53]	Ozveren et al.	2019	Retrospective	636/6-15	319 males 317 females	Northwestern Türkiye	Willems-Cameriere methods	Although Cameriere's method provided a better percentage of accuracy, both methods seem to be satisfactory for DA estimation for children in the Thrace region. When dental age assessment is required for criminal cases combined usage of Willems' and Cameriere's methods may be wiser.

DA: Dental age

Geographically, the studies encompassed a broad representation of Türkiye's regions, though some areas were more frequently studied than others. Northwestern Türkiye and Eastern Türkiye were the most represented regions, collectively accounting for more than half of the included studies. Southern Türkiye, Central Anatolia, and the Black Sea region were moderately represented, while studies from Northeastern Türkiye, Southwestern Türkiye, and Thrace were relatively fewer in number. Several investigations were localized to specific cities such as Ankara, İstanbul, Konya, Karaman, and Isparta, while others covered broader regional populations (e.g., Western Türkiye, Eastern Anatolia, Central and Eastern Türkiye). This geographical diversity allows for comparative insights but also highlights the uneven distribution of data across different parts of the country.

SAMPLE SIZES AND AGE RANGES

The sample sizes of the included studies varied considerably, ranging from as few as 150 participants to as many as 1,878.[32,46] The median sample size was approximately 800, with most studies including between 500-1,000 participants. All studies included both male and female subjects, and the sex distribution was generally balanced, with no single study exhibiting a disproportionate bias toward one sex.

The age ranges investigated spanned from early childhood to late adolescence, with the youngest participants being 2.2 years old and the oldest 18 years old.[26,42,44,51] However, the majority of studies concentrated on school-age children and adolescents, typically between 5-16 years. Several studies targeted narrower age groups (e.g., 6-14 years, 7-15 years) to examine developmental stages more precisely, while others employed broader ranges to evaluate the applicability of dental age estimation methods across multiple growth phases. This variation in age range and sample size reflects the methodological flexibility of dental age estimation research, while also allowing for region-specific comparisons of developmental trends in the Turkish pediatric population.

METHODS USED FOR DENTAL AGE ESTIMATION

Across the 30 included studies, a variety of dental age estimation methods were applied, all based on panoramic radiographic evaluation. The most frequently used techniques were the Demirjian, Willems, Nolla, and Cameriere methods, either alone or in combination. Several studies also employed modified or regionally adapted versions, such as the Cameriere-European formula, Blenkin-Evans, Bedek, Haavikko, and the London Atlas. In certain cases, newer or less widely used models were tested alongside established methods to determine their suitability for the Turkish pediatric population.

Multiple-method comparisons were common, with many studies directly contrasting 2 or more techniques to assess relative accuracy. For instance, several investigations found Willems to be more accurate than Demirjian in specific regions, while others reported superior performance of Cameriere-based methods, particularly the European adaptation, in minimizing age estimation bias.[27,29,32,34,38,41,44,46,50,53] Conversely, Nolla and Haavikko methods were found to yield better results in some localized populations, underscoring the importance of regional calibration.[24,28,35,37] The London Atlas, though less frequently applied, was noted for its practicality and comparable accuracy in certain contexts.[33]

This diversity of methods reflects both the historical reliance on well-established approaches and the ongoing search for population-specific modifications that address regional variations in dental maturation.

FINDINGS BY METHOD

The comparative performance of dental age estimation methods varied notably across regions and age groups. Willems emerged as one of the most frequently favored methods, with multiple studies reporting its superior accuracy over Demirjian, particularly in Northwestern, Southern, and Eastern Türkiye.[27,29,38,44,46] In several of these studies, Willems demonstrated minimal bias in age estimation, though in some cases it tended to slightly overestimate chronological age.

The Cameriere method, including its European adaptation, was also widely recognized for its accu-

racy.[32,34,41,50,53] In Eastern and Northwestern Türkiye, Cameriere-European often outperformed other methods, producing estimates closest to actual chronological age in both sexes. Some studies noted that Cameriere's approach was less prone to systematic over- or underestimation, making it especially suitable for forensic applications. However, in a few instances, Cameriere slightly underestimated age in older adolescents.

The Nolla method showed strong performance in certain regions, such as Northeastern and Eastern Türkiye, where it provided closer approximations than Demirjian.[24,28,37] Conversely, in some populations, Nolla's method demonstrated a tendency to underestimate age, highlighting the need for region-specific validation. Haavikko was identified as particularly accurate in Northwestern Türkiye, surpassing both London Atlas and Cameriere-European in one study.[35]

Less commonly used methods, such as the London Atlas, Blenkin-Evans, and Bedek models, also showed promise. The London Atlas was valued for its ease of use and comparable accuracy to Willems in Eastern Türkiye.[33] Blenkin-Evans often ranked among the most accurate methods in Northwestern Anatolia, while Bedek models produced competitive results in Eastern Türkiye, though slightly less accurate than Cameriere-European.[34,45]

Collectively, these findings underscore that no single method is universally optimal across all Turkish subpopulations. Instead, accuracy is influenced by a combination of regional developmental patterns, age distribution, and sex differences, reinforcing the importance of selecting methods validated for specific populations.

SUMMARY OF KEY FINDINGS

This review identified 30 retrospective studies published between 2010-2025 that investigated forensic dental age estimation in Turkish children using panoramic radiographs. The included research covered a wide geographical distribution across Türkiye, with Northwestern and Eastern regions most frequently represented. Sample sizes ranged from 150 to 1,878 participants, and age ranges spanned from early childhood to late adolescence, though most studies concentrated on the 5-16 age group. Various age estimation methods were applied, with Willems, Cameriere, Nolla, and Demirjian being the most common, often used in combination for comparative purposes. No single method consistently outperformed others across all populations; instead, accuracy varied by region, sex, and age group. Several studies emphasized the necessity of population-specific standards, while 2 unique investigations explored climatic influences and secular trends in dental maturation.

DISCUSSION

This review synthesized evidence from 30 retrospective studies published between 2010-2025 that evaluated forensic dental age estimation methods in Turkish children using panoramic radiographs. The included research demonstrated substantial methodological diversity, with a wide range of age estimation techniques applied across different regions of Türkiye. While commonly used approaches such as Willems, Cameriere, Nolla, and Demirjian methods appeared in the majority of studies, their performance varied according to geographical location, sex, and age group. No single method consistently outperformed the others across all populations, and many studies emphasized the need for population-specific calibration. These findings underscore the complexity of applying standardized dental age estimation techniques to a heterogeneous population and highlight the importance of considering demographic and regional factors in forensic practice.

When compared with studies conducted in other populations, the variability observed in the Turkish pediatric sample aligns with global findings that dental maturation rates differ across ethnic, genetic, and environmental backgrounds.[54,55] For example, several international investigations have reported that the Willems method generally yields greater accuracy than the Demirjian method in different populations, whereas Cameriere's formula often provides more precise results in Southern European and Mediterranean cohorts.[22,56-64] Similar patterns emerged in the present review, where Willems and Cameriere-based approaches frequently outperformed Demirjian in Turkish children. However, in

certain Turkish subpopulations, methods such as Nolla or Haavikko produced closer estimates to chronological age, a finding that contrasts with some international data where these methods tend to underestimate age.[65-67] These discrepancies reinforce the necessity of validating dental age estimation techniques within the specific population in which they are to be applied, particularly in forensic contexts where small deviations may have significant legal implications.

Regional and demographic influences emerged as important factors affecting the accuracy of dental age estimation in the Turkish pediatric population. Several studies reported significant regional differences, suggesting that factors such as nutrition, socioeconomic status, and environmental conditions may influence dental development rates. In this context, Cantekin et al. provided direct evidence of climatic effects, demonstrating that children from Central Anatolia were 0.2 to 3.0 years more advanced in dental maturity than their Eastern Anatolian counterparts.[47] Similarly, Kaygisiz et al. investigated secular changes in dental maturation over a 30-year period, finding no significant positive trend across decades but noting sex-specific differences in certain age groups, particularly among those born in the 2000s.[49] These findings indicate that both geographical and temporal factors can influence the applicability of standard dental age estimation methods, underscoring the need for localized calibration when methods are applied in forensic casework involving Turkish children.

From a forensic perspective, the selection of an appropriate dental age estimation method is critical, as even small deviations can impact legal decisions regarding criminal responsibility, asylum applications, and age-related rights. The findings of this review suggest that Willems and Cameriere-based methods, particularly the Cameriere-European formula, may offer more reliable estimates in many Turkish subpopulations, although their performance is not universally consistent. In some studies, the combined application of 2 methods -most notably Willems and Cameriere- was proposed to enhance accuracy, especially in cases where 1 method tends to overestimate and the other underestimates chronological age. However, while such combined approaches may reduce bias, they also increase the complexity and time required for assessment, which may limit their practicality in routine forensic workflows. Ultimately, the choice of method should be guided by prior validation in the target population, regional developmental characteristics, and the specific requirements of the forensic context.

The noticeable increase in publications between 2020-2025 may be explained not only by the growing interest in forensic sciences but also by the impact of the coronavirus diseases-2019 pandemic, which encouraged retrospective designs. Despite several methodological strengths such as large sample sizes and wide regional coverage, existing methods did not always yield consistent accuracy in Turkish children. This inconsistency is likely related to population differences in dental maturation influenced by genetic, nutritional, and environmental factors. To close this gap, population-specific calibration and the development of reference standards adapted to Turkish children are necessary, ideally through multicenter, prospective validation studies.

This review has several limitations that should be acknowledged. First, all included studies were retrospective and relied solely on panoramic radiographs, which, while practical, limit the generalizability of the findings and preclude comparison with more advanced imaging modalities. Second, certain geographical regions of Türkiye were underrepresented or absent, restricting the ability to establish nationwide standards. Third, although inclusion criteria required forensic purposes, methodological heterogeneity persisted across studies in terms of calibration and reporting. In addition, unusual cases -such as the youngest reported participant being 2.2 years old- highlight potential inconsistencies in study methodologies, and such extreme values should be interpreted with caution. Finally, although this work was conducted as a systematic review, no meta-analysis was performed due to the substantial methodological and outcome heterogeneity across the included studies. Consequently, the synthesis was limited to a structured descriptive summary rather than quantitative pooling.

CONCLUSION

This review provides a comprehensive synthesis of existing literature on forensic dental age estimation in Turkish children based on panoramic radiographs. The analysis of 30 retrospective studies published between 2010-2025 revealed substantial variability in method performance across different regions, age groups, and sexes. While techniques such as Willems, Cameriere, Nolla, and Demirjian remain the most frequently applied, no single method consistently yielded optimal results for all subpopulations. Regional differences, as well as environmental and temporal factors, appear to influence dental maturation, underscoring the necessity of developing population-specific calibration standards for accurate age assessment.

From a forensic perspective, the selection of an appropriate dental age estimation method carries significant implications for legal decision-making, particularly in cases involving age thresholds for criminal responsibility, immigration, or civil rights. The evidence suggests that methods such as Willems and Cameriere-European often perform well in Turkish children, yet their accuracy is not universally applicable. Combining complementary methods may improve estimation reliability, though this approach must be balanced against the practical demands of forensic workflows.

The findings of this review highlight critical gaps in the literature, including the underrepresentation of certain geographical regions and the absence of prospective, multicenter studies. Addressing these gaps will require coordinated research efforts that integrate diverse regional data, apply rigorous validation processes, and explore the influence of socio-environmental factors on dental maturation. Establishing standardized, population-specific protocols will not only enhance the scientific validity of dental age estimation in Türkiye but also strengthen its application as a robust and defensible tool in forensic practice.

By mapping the full scope of existing research and identifying both methodological strengths and limitations, this review provides a foundational reference for forensic odontologists, policymakers, and researchers aiming to refine and standardize dental age estimation practices for Turkish children.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

This study is entirely author's own work and no other author contribution.

REFERENCES

1. Airlie M, Robertson J, Krosch MN, Brooks E. Contemporary issues in forensic science-worldwide survey results. Forensic Sci Int. 2021;320:110704. [PubMed]
2. Jayakrishnan JM, Reddy J, Vinod Kumar RB. Role of forensic odontology and anthropology in the identification of human remains. J Oral Maxillofac Pathol. 2021;25(3):543-7. [PubMed] [PMC]
3. Emam NM. Role of forensic odontology in identification of persons: a review article. Cureus. 2024;16(3):e56570. [Crossref] [PubMed] [PMC]
4. Espinoza-Silva PV, López-Lázaro S, Fonseca GM. Forensic odontology and dental age estimation research: a scoping review a decade after the NAS report on strengthening forensic science. Forensic Sci Med Pathol. 2023;19(2):224-35. [Crossref] [PubMed]
5. Neculqueo-Millán J, Boikanyo M, Fonseca GM. Forensic odontology in the search of dental evidence at the scene of events with incinerated victims: a scoping review. Forensic Sci Med Pathol. 2025;21(3):1416-27. [PubMed]
6. Sharon E, Engel I, Beyth N, Malihi L, Kahana T. Insights from the 7th of October massacre: forensic odontology in mass disasters. Forensic Sci Int. 2025;368:112394. [Crossref] [PubMed]
7. Sebastian S, Franco A, Mânica S. Intersection of forensic odontology and psychology. J Forensic Odontostomatol. 2023;41(1):2-18. [PubMed] [PMC]

8. Christoloukas N, Mitsea A. The CSI effect in forensic odontology. A systematic review. J Forensic Odontostomatol. 2022;40(2):38-43. [Crossref] [PubMed] [PMC]
9. Balachander N, Babu NA, Jimson S, Priyadharsini C, Masthan KM. Evolution of forensic odontology: an overview. J Pharm Bioallied Sci. 2015;7(Suppl 1):S176-80. [PubMed] [PMC]
10. Hill AJ, Hewson I, Lain R. The role of the forensic odontologist in disaster victim identification: lessons for management. Forensic Sci Int. 2011;205(1-3):44-7. [Crossref] [PubMed]
11. Khorate MM, Dinkar AD, Ahmed J. Accuracy of age estimation methods from orthopantomograph in forensic odontology: a comparative study. Forensic Sci Int. 2014;234:184.e1-8. [PubMed]
12. Sezer B, Çarıkçıoğlu B, Kargül B. Dental age and tooth development in children with molar-incisor hypomineralization: a case-control study. Arch Oral Biol. 2022;134:105325. [Crossref] [PubMed]
13. Macha M, Lamba B, Avula JSS, Muthineni S, Margana PGJS, Chitoori P. Estimation of correlation between chronological age, skeletal age and dental age in children- a cross-sectional study. J Clin Diagn Res. 2017;11(9):ZC01-4. Erratum in: J Clin Diagn Res. 2018;12(6):ZZ02. [Crossref] [PubMed] [PMC]
14. Güler ÖÇ, Deniz Y, Arslan S. Comparison of dental and skeletal age estimating methods in children. Acta Stomatol Croat. 2023;57(1):2-11. [Crossref] [PubMed] [PMC]
15. Abd Elmaguid Kaka R, Ismail Mohamed Haiba M, Abd Elmoneim Sheta A, Hassan Salama N, Mostafa Enany N. Age estimation using dental and hand-wrist radiography among a sample of Egyptian children. Sci Rep. 2025;15(1):1056. [PubMed] [PMC]
16. Schulz R, Zwiesigk P, Schiborr M, Schmidt S, Schmeling A. Ultrasound studies on the time course of clavicular ossification. Int J Legal Med. 2008;122(2):163-7. [Crossref] [PubMed]
17. Gelbrich B, Carl C, Gelbrich G. Comparison of three methods to estimate dental age in children. Clin Oral Investig. 2020;24(7):2469-75. [Crossref] [PubMed]
18. Merdietio Boedi R, Shepherd S, Mânica S, Franco A. CBCT in dental age estimation: a systematic review and meta analysis. Dentomaxillofac Radiol. 2022;51(4):20210335.
19. Niño-Sandoval TC, Doria-Martinez AM, Escobar RAV, Sánchez EL, Rojas IB, Álvarez LCV, et al. Efficacy of the methods of age determination using artificial intelligence in panoramic radiographs-a systematic review. Int J Legal Med. 2024;138(4):1459-96. [Crossref] [PubMed]
20. Franco A, de Oliveira MN, Campos Vidigal MT, Blumenberg C, Pinheiro AA, Paranhos LR. Assessment of dental age estimation methods applied to Brazilian children: a systematic review and meta-analysis. Dentomaxillofac Radiol. 2021;50(2):20200128.
21. Cadenas de Llano-Pérula M, Kihara E, Thevissen P, Nyamunga D, Fieuws S, Kanini M, et al. Validating dental age estimation in Kenyan black children and adolescents using the Willems method. Med Sci Law. 2021;61(3):180-5. [Crossref] [PubMed]
22. Paz Cortés MM, Rojo R, Alía García E, Mourelle Martínez MR. Accuracy assessment of dental age estimation with the Willems, Demirjian and Nolla methods in Spanish children: comparative cross-sectional study. BMC Pediatr. 2020;20(1):361. [Crossref] [PubMed] [PMC]
23. Markovic E, Marinkovic N, Zelic K, Milovanovic P, Djuric M, Nedeljkovic N. Dental age estimation according to European Formula and Willems Method: comparison between children with and without cleft lip and palate. Cleft Palate Craniofac J. 2021;58(5):612-8. [PubMed]
24. Kırzıoğlu Z, Ceyhan D. Accuracy of different dental age estimation methods on Turkish children. Forensic Sci Int. 2012;216(1-3):61-7. [Crossref] [PubMed]
25. Altunsoy M, Nur BG, Akkemik O, Ok E, Evcil MS. Applicability of the Demirjian method for dental age estimation in western Turkish children. Acta Odontol Scand. 2015;73(2):121-5. [Crossref] [PubMed]
26. Gungor OE, Kale B, Celikoglu M, Gungor AY, Sari Z. Validity of the Demirjian method for dental age estimation for Southern Turkish children. Niger J Clin Pract. 2015;18(5):616-9. [Crossref] [PubMed]
27. Ozveren N, Serindere G. Comparison of the applicability of Demirjian and Willems methods for dental age estimation in children from the Thrace region, Turkey. Forensic Sci Int. 2018;285:38-43. [PubMed]
28. Nur B, Kusgoz A, Bayram M, Celikoglu M, Nur M, Kayipmaz S, et al. Validity of demirjian and nolla methods for dental age estimation for Northeastern Turkish children aged 5-16 years old. Med Oral Patol Oral Cir Bucal. 2012;17(5):e871-7. [Crossref] [PubMed] [PMC]
29. Apaydin BK, Yasar F. Accuracy of the Demirjian, Willems and Cameriere methods of estimating dental age on Turkish children. Niger J Clin Pract. 2018;21(3):257-63. [Crossref] [PubMed]
30. Celikoglu M, Cantekin K, Ceylan I. Dental age assessment: the applicability of Demirjian method in eastern Turkish children. J Forensic Sci. 2011;56 Suppl 1:S220-2. [PubMed]
31. Erdem AP, Yamac E, Erdem MA, Sepet E, Aytepe Z. A new method to estimate dental age. Acta Odontol Scand. 2013;71(3-4):590-8. [Crossref] [PubMed]
32. Kış HC, Görürgöz C, Başol M, Canger EM, Öztaş B. Evaluation of the Willems and Cameriere's dental age estimation methods in Turkish children-a modified version of Cameriere's method. Forensic Sci Int: Rep. 2020;2:100105. [Crossref]
33. Koç A, Özlek E, Öner Talmaç AG. Accuracy of the London atlas, Willems, and Nolla methods for dental age estimation: a cross-sectional study on Eastern Turkish children. Clin Oral Investig. 2021;25(8):4833-40. [Crossref] [PubMed]
34. Gümüşboğa ZŞ, Duruk G, Özdemir E, Aydan T, Kırgın AŞ. An investigation of the validity of the Bedek models and Cameriere-European formula used in dental age prediction in Turkish children. BMC Oral Health. 2024;24(1):1396. [PubMed] [PMC]
35. Sezer B, Çarıkçıoğlu B. Accuracy of the London Atlas, Haavikko's Method and Cameriere's European Formula of dental age estimation in Turkish children. Leg Med (Tokyo). 2022;54:101991. [Crossref] [PubMed]
36. Onat Altan H, Altan A, Bilgiç F, Akıncı Sözer Ö, Damlar İ. The applicability of Willems' method for age estimation in southern Turkish children: a preliminary study. J Forensic Leg Med. 2016;38:24-7. [Crossref] [PubMed]
37. Duruk G, Gundogdu Ozdal TP, Duman S. Accuracy of age estimation with Demirjian and Nolla methods in Eastern Turkish children aged 3-17 years old. Eur Oral Res. 2022;56(2):80-7. [PubMed] [PMC]
38. Altan H, Altan A, Akinci Sozer O. Dental age estimation in southern Turkish children: comparison of Demirjian and Willems methods. Iran J Pediatr. 2017;27(6):e11726. [Crossref]
39. Karataş O, Öztürk F, Dedeoğlu N, Çolak C, Altun O. Dental age assessment: The applicability of Demirjian method in southwestern of eastern Anatolia region Turkish children. Cumhuriyet Dent J. 2012;15(2):130-7. [Crossref]
40. Çarıkçıoğlu B, Sezer B. Dental age estimation with fewer than mandibular seven teeth: an accuracy study of Bedek models in Turkish children. Clin Oral Investig. 2022;26(9):5773-84. [Crossref] [PubMed]
41. Hato E, Coşgun A, Altan H. Comperative evaluation of Nolla, Willems and Cameriere methods for age estimation of Turkish children in the Central Black Sea Region: a preliminary study. J Forensic Leg Med. 2022;91:102400. [Crossref] [PubMed]
42. Celik S, Zeren C, Celikel A, Yengil E, Altan A. Applicability of the Demirjian method for dental assessment of southern Turkish children. J Forensic Leg Med. 2014;25:1-5. [Crossref] [PubMed]
43. Gulsahi A, Tirali RE, Cehreli SB, De Luca S, Ferrante L, Cameriere R. The reliability of Cameriere's method in Turkish children: a preliminary report. Forensic Sci Int. 2015;249:319.e1-5. [Crossref] [PubMed]
44. Akkaya N, Yilanci HÖ, Göksülük D. Applicability of Demirjian's four methods and Willems method for age estimation in a sample of Turkish children. Leg Med (Tokyo). 2015;17(5):355-9. [Crossref] [PubMed]

45. Çarıkçıoğlu B, Değirmenci A. Accuracy of the radiographic methods of Willems, Cameriere and Blenkin-Evans on age estimation for Turkish children in the northwest Anatolia region. Aust J Forensic Sci. 2023;55(2):156-67. [Crossref]

46. İzgi E, Namdar Pekiner FM. Accuracy of dental and chronological age estimation in A Sample Turkish caucasion children: comparison of Demirjian's and Willems Methods. Clin Exp Health Sci. 2023;13:808-14. [Crossref]

47. Cantekin K, Ercan Sekerci A, Peduk K, Delikan E, Ozakar Ílday N, Demirbuga S, et al. Dental age assessment for different climatic regions. Am J Forensic Med Pathol. 2014;35(3):197-200. [Crossref] [PubMed]

48. Şahin TN, Güleç M. Evaluation of the accuracy of Cameriere, modified Cameriere and Willems and Blenkin-Evans Methods for Turkish children. Int Dent J. 2025;75(1):295-304. [Crossref] [PubMed] [PMC]

49. Kaygisiz E, Uzuner FD, Yeniay A, Darendeliler N. Secular trend in the maturation of permanent teeth in a sample of Turkish children over the past 30 years. Forensic Sci Int. 2016;259:155-60. [Crossref] [PubMed]

50. Çarıkçıoğlu B, Sezer B. Evaluation of the accuracy of Nolla, Cameriere-European, and Blenkin-Evans methods for dental age estimation of Turkish children. Med Sci Law. 2025:258024251365371. [PubMed]

51. Miloglu O, Celikoglu M, Dane A, Cantekin K, Yilmaz AB. Is the assessment of dental age by the Nolla method valid for eastern Turkish children? J Forensic Sci. 2011;56(4):1025-8. [Crossref] [PubMed]

52. Ercalikyalcinkaya S, Dumlu A, Bekiroglu N, Kizilyel G, Kargul B. Demirjian's system for estimating dental age among Northwestern Turkish children aged 4-16 years. Eur J Paediatr Dent. 2013;14(3):225-30. [PubMed]

53. Ozveren N, Serindere G, Meric P, Cameriere R. A comparison of the accuracy of Willems' and Cameriere's methods based on panoramic radiography. Forensic Sci Int. 2019;302:109912. [PubMed]

54. Adams DM, Ralston CE, Sussman RA, Heim K, Bethard JD. Impact of population-specific dental development on age estimation using dental atlases. Am J Phys Anthropol. 2019;168(1):190-9. [Crossref] [PubMed]

55. Jayaraman J, Wong HM, Roberts GJ, King NM, Cardoso HFV, Velusamy P, et al. Age estimation in three distinct east Asian population groups using southern Han Chinese dental reference dataset. BMC Oral Health. 2019;19(1):242. [Crossref] [PubMed] [PMC]

56. Esan TA, Yengopal V, Schepartz LA. The Demirjian versus the Willems method for dental age estimation in different populations: a meta-analysis of published studies. PLoS One. 2017;12(11):e0186682. [Crossref] [PubMed] [PMC]

57. Vieira I, Pereira ML, Caldas IM. The Applicability of the Demirjian and Willems standards to age estimation of 6-9-year-old Portuguese Children. Humans. 2025;5(1):6. [Crossref]

58. Sehrawat JS, Singh M. Willems method of dental age estimation in children: a systematic review and meta-analysis. J Forensic Leg Med. 2017;52:122-9. [Crossref] [PubMed]

59. Mohd Yusof MYP, Wan Mokhtar I, Rajasekharan S, Overholser R, Martens L. Performance of Willem's dental age estimation method in children: a systematic review and meta-analysis. Forensic Sci Int. 2017;280:245.e1-245.e10. [Crossref] [PubMed]

60. Spinas E, Melis G, Zerman N, De Luca S, Cameriere R. Age assessment in children and adolescents by measuring the open apices in teeth: a new Sardinian formula. Dent J (Basel). 2022;10(4):50. [Crossref] [PubMed] [PMC]

61. Cameriere R, Ferrante L, Ermenc B, Mirtella D, Strus K. Age estimation using carpals: study of a Slovenian sample to test Cameriere's method. Forensic Sci Int. 2008;174(2-3):178-81. [Crossref] [PubMed]

62. Zelic K, Marinkovic N, Milovanovic P, Cameriere R, Djuric M, Nedeljkovic N. Age estimation in children based on open apices measurement in the Serbian population: Belgrade Age Formula (BAF). Ann Hum Biol. 2020;47(3):229-36. [Crossref] [PubMed]

63. Pinchi V, Norelli GA, Pradella F, Vitale G, Rugo D, Nieri M. Comparison of the applicability of four odontological methods for age estimation of the 14 years legal threshold in a sample of Italian adolescents. J Forensic Odontostomatol. 2012;30(2):17-25. [Crossref] [PubMed] [PMC]

64. Hostiuc S, Diaconescu I, Rusu MC, Negoi I. Age estimation using the Cameriere methods of open apices: a meta-analysis. Healthcare (Basel). 2021;9(2):237. [Crossref] [PubMed] [PMC]

65. Paz Cortés MM, Rojo R, Mourelle Martínez MR, Dieguez Pérez M, Prados-Frutos JC. Evaluation of the accuracy of the Nolla method for the estimation of dental age of children between 4-14 years old in Spain: a radiographic study. Forensic Sci Int. 2019;301:318-25. [PubMed]

66. Melo M, Ata-Ali J. Accuracy of the estimation of dental age in comparison with chronological age in a Spanish sample of 2641 living subjects using the Demirjian and Nolla methods. Forensic Sci Int. 2017;270:276.e1-e7. [Crossref] [PubMed]

67. Patnana AK, Vabbalareddy RS, V Vanga NR. Evaluating the reliability of three different dental age estimation methods in visakhapatnam children. Int J Clin Pediatr Dent. 2014;7(3):186-91. [Crossref] [PubMed] [PMC]