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# Sixty years of research in dental age estimation: a bibliometric study

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## Abstract

**Background** Dental age estimation (DAE) research has grown rapidly and became one of the biggest topics in forensic odontology. This study aimed to evaluate the DAE research trends over the span of 60 years using bibliometric analysis.

**Methods** Sampling was performed in the Scopus database using a search string (“Dental Age Estimation” OR “Age Determination by Teeth”) to detect DAE-related studies. The search was performed from inception to the year 2022. A data-cleaning intervention using a fuzzy-matching technique was done to unify the author and affiliation name variations.

**Results** The initial search returned 1638 articles, years of publication ranging from 1964 to 2022, with an approximate growth rate of 5.9% a year. Source analysis showed that most of the top article sources were Forensic Science International ( $n = 200$ ). Cameriere R presents the overall highest score (77 articles, Local h-index 30). Authors from Shanghai Jiao Tong University produced the highest number of publications ( $n = 111$ ). The most locally cited study was “A New System of Dental Age Assessment” by Demirjian et al. (Hum Biol 45:211-227, 1973) ( $n = 1507$ ). The trending topics analysis shows that earlier DAE studies were focused on dental regressive changes and later changed focus to utilizing technological advancements. Institutions and Author’s collaborations were also found to be internationally diverse with 20.82% of the articles being a product of international co-authorships.

**Conclusions** DAE research has grown rapidly helped by multiple advancements in various technological ends. Along with the high demand for DAE analysis, authors and publishers need to continually improve their standards for their respective research and reporting and continue to increase collaboration.

**Keywords** Bibliometrics, Age Determination by Teeth, Forensic dentistry, Forensic odontology, Dental research

## Background

Dental age estimation (DAE) is one of the branches of forensic odontology, which aims to provide an estimation of an individual chronological age through an age-related dental variable (Greene et al. 2013). DAE methodologies require a firm quality assurance to reach a reliable and reproducible approach, starting from population sampling to the creation of models or tables. Therefore, it is essential that the forefront of DAE methodologists publish their results in peer-reviewed journals. The need to make scientific evidence available to the academic community is also corroborated by legal mechanisms. According to Daubert’s standards

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that rule the admissibility of evidence in Court in certain jurisdictions, methodologies used to produce evidence must be subjected to peer review and publication (among other requirements) (Lesciotto 2015). Moreover, Daubert's standards also highlight the importance of knowing the method's error rates before presenting forensic evidence (Fradella et al. 2003). This is especially relevant in the field of DAE because forensic casuistic has increased worldwide because of globalization (Thevissen et al. 2010b, 2009) and the influx of undocumented immigrants (Manica and Gorza 2019). This phenomenon creates a need for researchers to validate methodologies to calibrate models or identify error rates from other studies in their own population of interest (Bittencourt et al. 2018; Franco et al. 2021; Liversidge 2015; Merdietio Boedi et al. 2022). Consequently, DAE research has grown rapidly, with multiple original methods, validations, and modifications, and became one of the biggest topics in forensic odontology (Liu et al. 2016).

The trend of an expanding research field needs to be analysed to understand properly how much a particular research branch — in this case, DAE — has grown, particularly using bibliometric analysis. Bibliometric analysis is one of the approaches in scholarly research to understand emerging trends, collaboration patterns, and research gaps in scientific discoveries (Donthu et al. 2021). Although similar research has been conducted in forensic odontology (Liu et al. 2016; Sengupta et al. 2020), a focused bibliometric study in DAE has not been conducted so far, specifically a large-scale analysis of DAE publications. Therefore, the present study aimed to evaluate the DAE research trends over the span of 60 years using bibliometric analysis.

## Methods

### Data extraction

This is an observational descriptive study with retrospective data collection. Sampling was performed in the Scopus database to retrieve the metadata from peer-reviewed research in the field of DAE. The search string used to detect DAE-related studies was (“Dental Age Estimation” OR “Age Determination by Teeth”). Both terms are part of the common glossary used to index DAE-related studies in reference databases. The search was performed from inception to the year 2022. Only studies written in the English language were included, as determined by the filter set on the Scopus search prompt. The data was accessed and exported on January 1st, 2023. Data detected in Scopus was exported in.csv format to RStudio (version 3.4.0, R Foundation for Statistical Computing, Vienna, Austria).

### Data cleaning

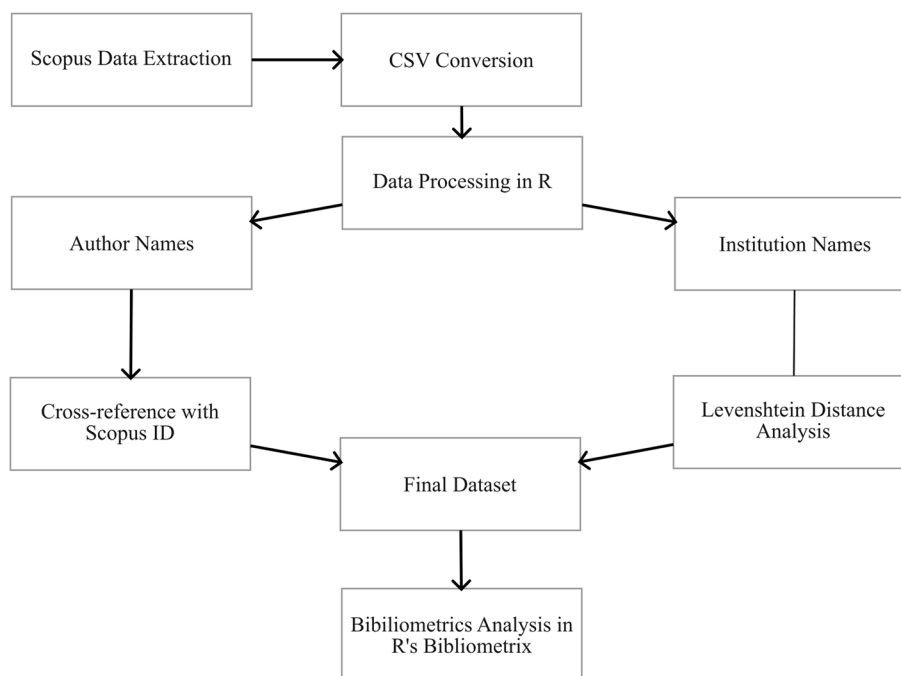
During the initial database export from Scopus, it was identified that multiple-character strings were not uniform due to variations in abbreviation, language, and characters. For example: (1) author “Różyło-Kalinowska, I” (Scopus ID 6603955520) was also listed as “Różyło-Kalinowska, I”; (2) “Katholieke Universiteit Leuven” was also listed as “KU Leuven” or “Catholic University Leuven”; and (3) “Universidade de São Paulo” was also listed as “University of São Paulo” and “University of Sao Paulo”. Therefore, a data uniformization protocol was conducted for the two most important data points: author names and affiliations (Fig. 1). This process was accomplished by two reviewers (RMB and AF).

Author names were standardized by cross-referencing the Scopus Author ID to the author names. If there were multiple authors with “similar” names coming from one Scopus Author ID, the names were joined together. However, the affiliations did not have the same unique number identifier as the authors recorded in the extracted bibliometric database. Therefore, a different approach was taken through fuzzy matching using *Levenshtein* Distance filtering (Levenshtein 1966). Fuzzy matching is a technique to identify a sequence of letters that are similar but not necessarily identical. It is often used to match data that has been entered into a database with inconsistent or incomplete information. Although fuzzy matching can work by various algorithms, *Levenshtein* distance was chosen in this research due to its filtering simplicity when compared to other edit distance measurements such as *Jaro-Winkler* or *Hamming* distance.

In the context of this study, *Levenshtein* distance was used to measure the similarity between different institution names. The affiliation name sequence was first converted to a number, and the shortest distance between the name was displayed. The threshold used for the *Levenshtein* distance filter was 0.1, and the filter results were joined together if a similar distance was detected for a particular naming sequence. This process was accomplished using the base R “*agrep*” function and *tidyverse* for filtering (Wickham et al. 2019).

### Bibliometric analysis

The bibliometric analysis — including citation analysis, collaboration, and ranking — was performed using the Bibliometrix package (Aria and Cuccurullo 2017). It is important to note that all the citation counts and impact (i.e. h-index) were calculated locally, which means that it only considered the citations within the included data. The keyword trending topics were pooled via Bibliometrix with a word minimum frequency of 15 and three words per year. Additionally, a list of synonyms was



**Fig. 1** Workflow diagram of the bibliometric analysis

created to combine similar keyword occurrences in the keyword trending topics. The collaboration of authors and institution network was visualized with Bibliometrix.

It is anticipated that despite the efforts to accurately represent the current research state of DAE by conducting data uniformization, some of the numbers presented in this study may not reflect the full status of the research topic due to the inherent complexities and nuances of the bibliometric dataset and analysis.

**Results**

The initial search returned 1638 articles, years of publication ranging from 1964 to 2022, with an approximate growth rate of 5.9% a year. The articles were written by 4357 authors, with an average of 4.11 authors per document. Almost 21% of the articles were a product of international co-authorships (Table 1).

**Source analysis**

Source analysis showed that most of the top article sources were focused on forensic and anthropological sciences, with the top source being Forensic Science International (Elsevier, ISSN: 1872–6283, *n* = 200). The top source with the highest local h-index was also found to be Forensic Science International, with a local h-index of 49 and a total citation count of 7841 (Table 2).

**Table 1** Overall information of dental age estimation studies

Main information	
Timespan	1964:2022
Documents	1638
Annual growth	5.9%
Average citation per doc	24.87
Authors	
Authors	4357
Authors of single-authored doc	166
Collaboration	
Single authored doc	207
Co-authors per doc	4.11
International co-authorships	20.82%

**Local impact**

Among all the authors’ calculated impact, Cameriere R (Scopus ID: 6507826165) presents- the overall highest score with 77 articles and a local h-index of 30 (Table 3). In the affiliation’s productivity, authors affiliated with Shanghai Jiao Tong University (Affiliation ID: 60025084) produced the highest number of articles totalling 111 authored articles (Table 4). Considering the country’s scientific productivity, India (*n* = 667) is the country that produced more articles, but the United Kingdom is the country with the highest local citation count of 4440 (Table 5).

**Table 2** Study sources and local impact

Article count		Article cited local		
Sources	n	Sources	h-index	n
Forensic Science International	200	Forensic Science International	49	7841
International Journal of Legal Medicine	151	American Journal of Physical Anthropology	38	4889
Journal of Forensic Sciences	86	International Journal of Legal Medicine	31	4300
American Journal of Physical Anthropology	82	Journal of Forensic Sciences	30	2448
Journal of Forensic Odonto-Stomatology	66	Journal of Forensic and Legal Medicine	21	1147
Journal of Forensic and Legal Medicine	61	Annals of Human Biology	16	968
Legal Medicine	42	Journal of Forensic Odonto-Stomatology	15	750
Archives of Oral Biology	26	Archives of Oral Biology	13	460
Annals of Human Biology	25	American Journal of Orthodontics and Dentofacial Orthopedics	12	522
Australian Journal of Forensic Sciences	23	European Journal of Oral Sciences	12	656

**Table 3** Author's productivity and local impact

No	Article count		Local impact			
	Authors	Articles	Authors	Local H-Index	Authors	Local Citation
1	Cameriere R	77	Cameriere R	30	Cameriere R	2583
2	Roberts G	36	Ferrante L	21	Liversidge H	2315
3	Galić I	34	Willems G	21	Demirjian A	2153
4	Ferrante L	33	Liversidge H	20	Goldstein H	1902
5	Liversidge H	32	Solheim T	20	Schmelting A	1798
6	Schmelting A	32	Thevissen P	19	Ferrante L	1654
7	Thevissen P	32	Galić I	18	Solheim T	1633
8	Willems G	26	Schmelting A	18	Tanner JM	1507
9	Franco A	25	Cingolani M	16	Willems G	1406
10	Olze A	25	De Luca S	16	Hector MP	1324
11	De Luca S	24	Olze A	16	Olze A	1244
12	Lucas V	23	Fieuws S	14	Cingolani M	1194
13	Solheim T	23	Roberts G	14	Geserick G	1119
14	Balla SB	22	Brkić H	13	Thevissen P	950
15	Cingolani M	19	Schulz R	13	Alqahtani S	922
16	Kvaal SI	19	Kvaal SI	12	Kvaal SI	860
17	Brkić H	18	Pfeiffer H	12	Galić I	840
18	Fieuws S	18	Lucas V	11	Dean MC	788
19	Schulz R	17	Chen T	10	Reisinger W	738
20	Guo Y-C	16	Guo Y-C	10	Hägg U	665

### Article and keywords

Article analysis revealed that most of the top 10 studies in DAE research were a study of a new DAE methodology (Table 6). The most locally cited study was “A New System of Dental Age Assessment” by Demirjian et al. (1973) (Demirjian et al. 1973), with a total local citation of 1507. The second most locally cited study was “Brief communication: The London atlas of human tooth development

and eruption” — a.k.a London Atlas — by AlQahtani et al. (2010) (AlQahtani et al. 2010) and followed by Lovejoy (1985) in “Dental wear in the Libben population: Its functional pattern and role in the determination of adult skeletal age at death” (Lovejoy 1985), which was also the only single-authored study in the top 10 articles.

Keywords occurrence analysis revealed that 23% of the studies were using “Forensic Odontology” as their main

**Table 4** Author's affiliation productivity counts

Affiliation	Articles
Shanghai Jiao Tong University	111
University of Macerata	109
Universidade De São Paulo	104
Katholieke Universiteit Leuven	102
Xi'an Jiao Tong University	92
Universitätsklinikum Münster	83
University of Western Australia	71
University of Zagreb	71
University of Granada	64
Panineeya Mahavidyalaya Institute of Dental Sciences	54

**Table 5** Author's country productivity and local impact

Article Count		Local citation count		
Region	<i>n</i>	Country	<i>n</i>	Average article citations
India	667	UK	4439	46.2
Italy	532	USA	4119	35.8
USA	443	Germany	3025	52.2
UK	382	Italy	2419	29.9
China	381	Belgium	1915	43.5
Brazil	358	India	1477	10
Germany	338	Turkey	1338	23.5
Japan	236	Sweden	1266	50.6
Turkey	235	Canada	1192	54.2
Belgium	217	Spain	1175	25.5

keyword ( $n=537$ ), followed by "Age Determination by Teeth" ( $n=467$ ), which was also the same MeSH term used for DAE research (Fig. 2). The trending topics analysis revealed that most of the DAE studies in the 1990s were focused on dental regressive changes. This trend then later evolved in the current days by utilizing more technological advancements, such as cone-beam computed tomography (CBCT) or machine learning (Fig. 3).

### Networks

Collaboration networks were visualized for citations, institutions, and authors. In the citations network, the majority of papers referenced "A New System of Dental Age Assessment" by Demirjian et al. (1973) as their study (Demirjian et al. 1973). Institution collaborations showed a diverse geographical location worldwide being the University of Macerata (Affiliation ID: 60027141), the most collaborative with other institutions from Europe (i.e. University of Zagreb [Affiliation ID: 60008408]), South America (i.e. Universidade de São Paulo [Affiliation ID:

60008088]), and Asia (i.e. Universitas Airlangga [Affiliation ID: 60069383]). Results for author collaborations were found to be internationally diverse — as seen in the 20.82% of international co-authorships, but there were small, isolated clusters from different authors from Chinese institutions. Even so, Liversidge HM (Scopus ID: 6602158831) was observed to be connected to every author cluster.

### Discussion

The research in DAE has experienced tremendous growth in recent years and it can be attributed to several factors. Firstly, the Internet has made it easier for academics to access and communicate with their peers, enabling fast and effective coordination between researchers as demonstrated by the amount of international collaboration in our dataset (20.82%) (Finch et al. 2013). Secondly, technological advancements have opened new possibilities for data transfer and methodology in various studies. Data transfer was made easier through digital imaging formats (i.e. DICOM) and although original methodology validations are still common for different populations, researchers have adapted these methodologies with the latest advancements. For example, Demirjian's staging has been adapted to include predictive modelling calculations (Galibourg et al. 2021) or image classification systems (Mohammad et al. 2021). Lastly, the demand for DAE reports in various identification matters, particularly in living individuals, has led to a continuous effort to support the legal systems worldwide, especially in protecting the rights of vulnerable age groups (i.e. children, pensioners) or geographic jurisdictions (i.e. asylum seekers) (Manica and Gorza 2019). These legal issues often require proper age assessment, and multiple DAE systems have been established to address this matter (Nuzzolese et al. 2011; Thevissen et al. 2010a; Zelic et al. 2016). These three factors have motivated the increase in DAE research and, as a result, increased the quality of the studies and moved the overall DAE studies to a more digital-based approach, utilizing mainly non-invasive approach through radiological data.

The top 10 sources in this field have a focus on not only forensic odontology, but mainly forensic medicine, anthropology, and human growth. These three fields are closely related to forensic odontology and DAE, as DAE is used to help identify individuals in forensics cases (Pretty and Sweet 2001), predict the age of archaeological sites in anthropology (Katzenberg et al. 2005), and serve as the basis for DAE methodology in children and juveniles in human growth studies. Although the human growth aspect did not contribute significantly to the topic of DAE methods for adults, which primarily rely on regressive dental changes, it remains the foundation of the most widely used DAE methods, such as staging

**Table 6** Top 10 most locally cited articles in dental age estimation research

Title	Author(s)	Year	Source	Cite n	Cite per year	Type of study	Observation
A New System of Dental Age Assessment	A. Demirjian et al	1973	Hum Biol	1507	29.55	Development staging	Radiographic
Brief communication: The London atlas of human tooth development and eruption	S.J. AlQahtani et al	2010	Am J Phys Anthropol	730	52.14	Development atlas	Radiographic
Dental wear in the Libben population: Its functional pattern and role in the determination of adult skeletal age at death	C.O Lovejoy	1985	Am J Phys Anthropol	553	14.18	Attrition staging	Clinical
Criteria for age estimation in living individuals	A. Schmeling et al	2008	Int J Leg Med	428	26.75	Research and Report recommendations	Report
New systems for dental maturity based on seven and four teeth	Demirjian and Goldstein	1976	Ann Hum Biol	395	8.23	Development staging	Radiographic
Age estimation of adults from dental radiographs	Kvaal Sl. et al	1995	Forensic Sci Int	360	12.341	Regressive changes measurement	Radiographic
Age estimation up to 16 years of age based on dental development	Gustafson and Koch	1974	Odontol Revy	288	5.76	Development staging	Radiographic
Accuracy of age estimation of radiographic methods using developing teeth	Maber et al	2006	Forensic Sci Int	262	14.56	Development staging comparison	Radiographic
Earliest evidence of modern human life history in North African early Homo sapiens	Smith et al	2007	Proc Natl Acad Sci	259	15.24	Anthropological microscopic evaluation	Clinical
Re-evaluation of the age at death of immature fossil hominids	Bromage and Dean	1985	Nature	257	6.59	Anthropological microscopic evaluation	Clinical

(Gunst et al. 2003), atlas (AlQahtani et al. 2014), or metric measurements (Cameriere et al. 2006).

In terms of author productivity and local impact, Cameriere R (Author ID: 6507826165) leads in all three aspects: article count, h-index, and citation count. Cameriere R is the founder of the *AgEstimation* project and the author of the well-known third-molar maturity index method (Cameriere et al. 2008), which has been used and recalibrated in various populations with satisfactory results. A study comparing its performance has been conducted and it is recommended that, even though the methodology can work for various populations and purposes (i.e. predictive or probabilistic modelling), a recalibration is necessary for the method to maintain its accuracy (De Micco et al. 2021). His methodology has had a significant impact on university rankings and trending topics. The University of Macerata (Università degli Studi di Macerata, Affiliation ID: 60027141) — the affiliation of Cameriere R — is ranked second in affiliation productivity (Table 4), and the trending topics analysis shows that the term

“Third-Molar Maturity Index” has been a trend from approximately 2018 to 2020 (Fig. 3).

The first ranking in affiliation productivity is Shanghai Jiao Tong University (Affiliation ID: 60025084), with the starting initial recorded research in 2013 by Yan et al. (2013) which studies the usability of Demirjian’s method in multiple populations through meta-analysis. It was suggested that there is a need for population-specific formula recalibration of this methodology (Yan et al. 2013). Additionally, the top locally cited article from Shanghai Jiao Tong University is an article by Ye et al. (2014) ( $n=40$ ), which studies Demirjian’s method and Willem’s formula in the Chinese children population (Ye et al. 2014).

The top 10 most locally cited articles give a glimpse of how wide the DAE research scope is. Although most of the articles focused on the modern population, there are also articles that used DAE in anthropology. The most locally cited article, “A New System of Dental Age Assessment” by Demirjian et al. (1973) was seen as a foundation of every modern DAE study (Demirjian et al. 1973). This can be observed in Fig. 4, that the most well-known



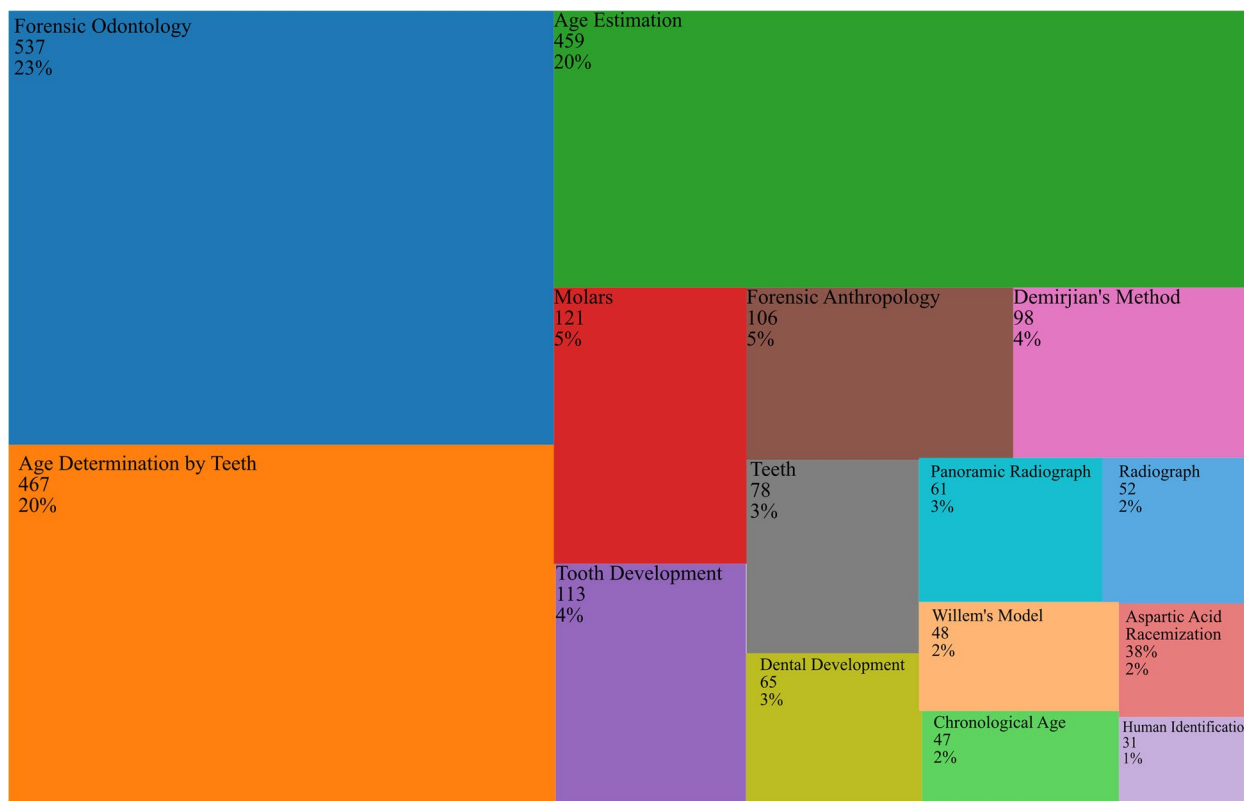


Fig. 2 Overall keyword count

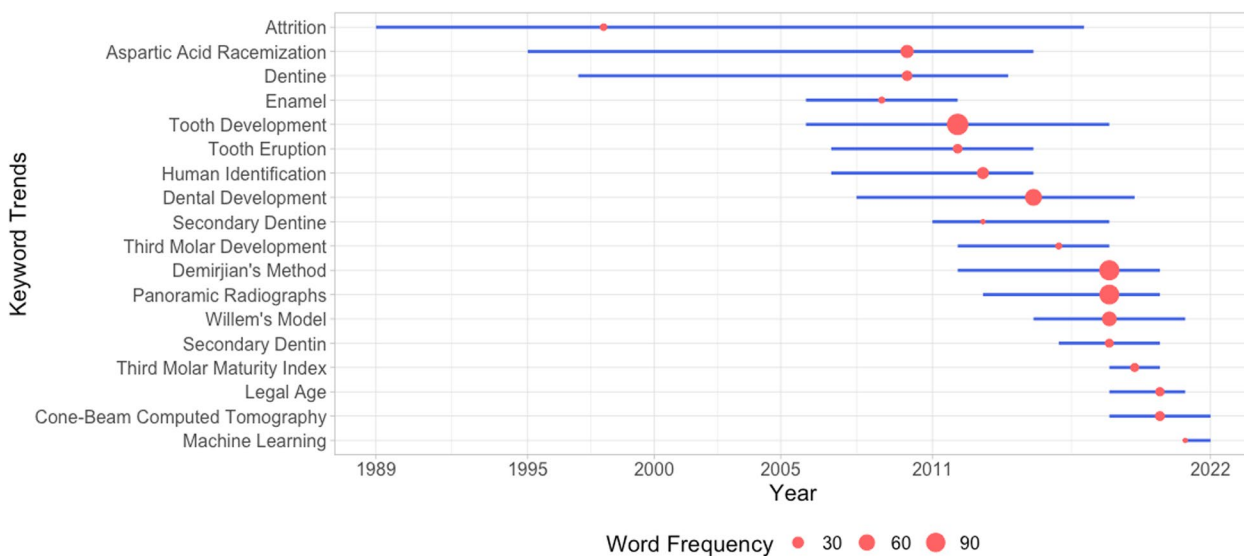
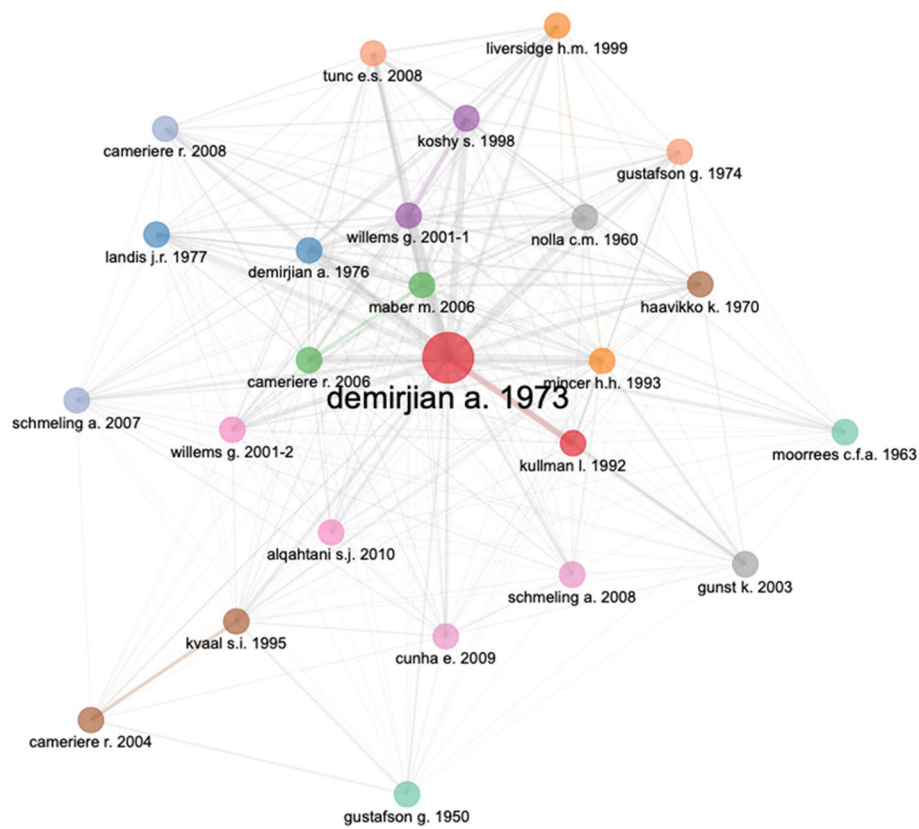


Fig. 3 Trending topic analysis based on keyword year occurrences

article in DAE uses Demirjian staging research as their reference. As explained before, the Demirjian staging method has been validated into multiple populations and adaptations using a modern statistical approach, and

other staging modifications. Additionally, most of the top articles focused on a non-invasive approach to obtain an estimated dental age as the usage of these methods is not limited to the deceased, but also to the living population.



**Fig. 4** Local co-citation network of dental age estimation studies. The naming follows the surname of the first author and followed by the publication year of the research

The connection between the authors and the institution is reflected in Figs. 5 and 6. The connection can be seen as a cluster of collaboration, either by similar study interest, organization, generational, or geographical language aspect. These aspects may create or separate the connection between researchers, as authors or institutions can have a specific interest in a certain subject or approach (i.e. legal age, third molar development, specific modalities). Additionally, most of the authors and institutions are connected through forms of an international organization, such as the International Organization for Forensic Odonto-Stomatology (IOFOS). IOFOS is an organization for forensic odontology expert to meet and refine the standardization of forensic odontology methodology, including DAE. Another prominent organization is “*Arbeitsgemeinschaft für Forensische Altersdiagnostik*” (AGFAD) led by Schmelting A. This organization gives an overall insight into age estimation in general and not necessarily in DAE. Even so, reports and standardization that come from AGFAD have played a major role in DAE research (Schmelting et al. 2008). This global research environment means that even though there are known variations of human dental changes throughout the population

worldwide (Liversidge 2008), most of the research questions are shared through collaborative research. As stated by Espinoza et al. (2022), these conditions give a very powerful incentive for methodology development through a form of international collaborations and multicentre-level studies (Espinoza-Silva et al. 2022).

The limitation of this study has resulted from the limitation of the academic database itself, or more accurately, the lack of standardization in data input. In this study, Scopus was chosen as the preferred database since Scopus offered a high-quality curated academic database to be used in a large-scale evaluative study (Baas et al. 2020). However, we observe multiple errors — in the author’s name or affiliation — in regard to the extracted database, which comes from a non-ASCII character and language. In the author’s name, it is considerably easier to unify the name due to the Scopus Author ID numbering. In terms of affiliations, Scopus also assign affiliation to a similar unique ID. Unfortunately, this information is not extracted from the data export, creating difficulties in data uniformization. We recommend that every bibliometric study runs a data cleaning to their database, since failing to unify the data may result in a misrepresented





current research condition. Furthermore, we noticed that early research has an inadequate filing system, which resulted in (1) the research itself not being exported/detected and (2) incomplete bibliometric analysis. Due to this limitation, certain research might not have been adequately catalogued in the database we exported for our study. As a result, the absence of earlier studies in our dataset may have gone undetected and created an impression that research on DAE began in 1964, which is not the case. One example of undetected research is Gustafson's influential work on adult DAE: "*Age Determination of Teeth*" (Gustafson 1950). The research itself is represented in our database as "cited research" in Fig. 4 but not in the overall database. This can be explained by the keyword index in Scopus for Gustafson's work that only used "*Age Factors*" and "*Tooth*" when related to the MeSH indexing system. Consequently, these partially indexed early studies made the trending topic analysis — which uses keywords — partially missing, with only studies from 1989 onward can be analysed (Fig. 3).

## Conclusions

DAE research trend has grown rapidly throughout the years. Together with advancements in various technological ends — such as advanced imaging technique and analysis, DAE research has evolved to a more robust methodology through validations and focused more on non-invasive techniques. The highly collaborative environment in DAE research shows that even though DAE methods were mostly population-specific, significant effort has been made between research centres to solve the variability problem, either by validation or the creation of a new DAE approach. Along with the high demand for DAE analysis, authors and publishers need to continually improve their standards for their respective research and reporting and continue to increase collaboration.

## Abbreviations

DAE	Dental age estimation
CBCT	Cone-beam computed tomography
OFOS	International Organization for Forensic Odonto-Stomatology (IOFOS)
AGFAD	Arbeitsgemeinschaft für Forensische Altersdiagnostik

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## Authors' contributions

RMB developed the main conceptual ideas and research structure, written the initial manuscript draft, material preparation, data collection, data analysis, and implementation of the computer code and programming. SM developed the main conceptual ideas and proof outline, verified the results from the bibliometric analysis, contributed to the final version of the manuscript, supervised the project, and oversaw overall direction and planning. AF developed the main conceptual ideas and proof outline, verified the results from the bibliometric analysis, performed the data verification, contributed to the final version of the manuscript, supervised the project, and oversaw overall direction and planning. All authors read and approved the final manuscript.

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## Availability of data and materials

Dataset generated from this research is available from the corresponding author upon a reasonable request.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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