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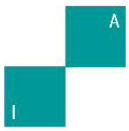

INTELIGENCIA ARTIFICIAL

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Artificial Intelligence (AI) in Dental Age Estimation Studies: A Scientometric Analysis

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Abstract: Dental age estimation (DAE) is important in age-related studies ranging from forensics, clinical dentistry and bioanthropology. DAE heavily relies on image analysis and morphometrics and has underwent academic scrutiny to improve its level of reliability and accuracy. The recent rise of artificial intelligence (AI) in data analysis allows accurate analysis without the influence of human error. As AI has penetrated DAE research, there is a lack of scientometric analysis regarding AI-driven DAE studies. This scientometric study presents an analysis of AI-driven DAE research based on data from the Scopus and Web of Science literature databases. This study examines various parameters, such as publication trends, prolific countries and research institutions, active journals and highly cited publications as well as highly used keywords pertaining to AI-driven DAE studies. Notably, though the niche area is fairly recent, there has been a substantial increase in the number of publications in AI-driven DAE research in the past few years. Countries such as China, Malaysia and South Korea are currently at the forefront of publications on the application of AI in DAE studies. This study also finds that a variety of journals ranging from dentistry, law, forensics and computer science are publishing studies on AI-driven DAE. Prominent keywords such as "age estimation","artificial intelligence" and age-group related keywords were amongst the dominant keywords used. This scientometric analysis provides an overview of studies pertaining to AI-driven DAE, which serves to help researchers stay informed regarding the latest research trend and may help identify possible research gaps.

Keywords: Dental Age Estimation, Age Determination by Teeth, Artificial Intelligence, Scientometric, ScientoPy.

1 Introduction

Dental age estimation (DAE) is one of the preferred age estimation methods as dental hard tissue, due to its durable biological structure, acts as a reliable age biomarker [1]. Dental hard tissues consists mainly of hydroxyapatite crystals, are the most indestructible components of the human body and may remain

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preserved for many years after death [2]. Moreover, teeth are documented to be resistant to external influence, as well as mechanical, thermal and chemical irritation [3]. DAE is essential in forensic and clinical settings as it provides valuable information for identifying human remains, establishing the age of individuals involved in legal cases, and determining the appropriate dental treatment for patients whose chronological age is unknown. Additionally, DAE can aid in assessing growth and development abnormalities, evaluating orthodontic treatment progress, and determining the eligibility of individuals for certain procedures or treatments based on their dental maturity [4]. Due to these factors, DAE studies strive for low error rates, higher age estimation accuracy, reliable predictability as well as practicality. The accuracy of DAE studies rely on several factors such as the biomarker used for age estimation as well as the technology or method used to estimate age from the chosen biomarkers. With regards to the technology or method used to estimate dental age, DAE can be conducted via a variety of methods such as morphological methods, biochemical methods or radiological methods [5]. These methods have their advantages and disadvantages and are used accordingly depending on the case and resources available.

The emergence of artificial intelligence (AI) in analysis has caught the world by storm and has influenced many areas of research and analysis. McCarthy (2004) defines "Artificial Intelligence" as "...the science and engineering of making intelligent machines..." whilst "Intelligence" is defined as "...the computational part of the ability to achieve goals in the world." [6]. However, in the current context of research and academia, AI is developed to plan, predict and solve different problems ranging from image analysis to speech recognition. Via training on a given set of data, AI is able to predict better results and help to solve complex problems with high accuracy [7].

As DAE is dependent on morphometric, image and data analysis, it is ideal to incorporate AI in DAE studies to increase accuracy and reliability. The application of AI in DAE studies impacts and influences a spectrum of subject areas, such as forensics, clinical judgement, bioanthroplogy and archeology. It is important to understand the AI-driven DAE research landscape in order to gain a holistic understanding of the key figures, current research trends and future research opportunities. In order to achieve this, this study aims to conduct a scientometric analysis to describe a birds-eye view of the research landscape pertaining to the incorporation of AI in DAE research in order to obtain a deeper understanding of the currently available literature. Scientometric analysis provides a birds-eye overview or the topic of interest, it identifies knowledge gaps, as well as identifies key contributors of the field [8, 9]. To achieve this, this study focuses on addressing the following research questions:

RQ1: What is the trend in the number of publications on AI-driven DAE studies in the last decade?
RQ2: Which countries and research institutions have been the most prolific in publishing AI-driven DAE studies?
RQ3: Which journals have published the highest number of articles related to AI-driven DAE research?
RQ4: What are the most highly cited publications in AI-driven DAE research, and what are their main contributions?
RQ5: What are the most frequently occurring keywords in AI-driven DAE studies?

2 Methodology

2.1 Dataset

Scientometric analysis consists of statistical methods used to measure research quality impact through the process of identifying, organising, and analysing the main components within a particular research field [10]. The scientometric method allows for the evaluation of contributions achieved by agents such as number of publications, countries, institutions, authors and keywords [11]. ScientoPy, an open-source Python script-based scientometric analysis tool was deployed to analyse the chosen bibliographical data [12]. The full source code, instructions manual, and example commands are made publicly available by the authors in the public repository: https://github.com/jpruiz84/ScientoPy. ScientoPy allows for automatic data synthesis which avoids potential bias as in individual studies [13]. In addition, VOSViewer,

a software for constructing and visualizing bibliometric networks, was used to conduct keyword network analyses [14].

Table 1: Keywords for Dataset Search

Database	Keywords
SCOPUS	(TITLE-ABS-KEY("age determination" OR " age estimation") AND TITLE-ABS-KEY("dental" OR "molar" OR "premolar" OR "incisor" OR "canine" OR "odontology" OR "panoramic radiograph" OR "orthopantomagram") AND TITLE-ABS-KEY("artificial intelligence" OR "deep learning" OR "machine learning" OR "neural network" OR "machine intelligence" OR "computational intelligence")) AND (LIMIT-TO (DOCTYPE,"ar"))
Clarivate Web of Science	(TS=("age determination" OR " age estimation") AND TS=("dental" OR "molar" OR "premolar" OR "incisor" OR "canine" OR "odontology" OR "panoramic radiograph" OR "orthopantomagram") AND TS=("artificial intelligence" OR "deep learning" OR "machine learning" OR "neural network" OR "machine intelligence" OR "computational intelligence")) AND (DT==("ARTICLE"))

For the scientometric analysis, two databases, Clarivate Web of Science (WoS) and SCOPUS, which are considered the world's largest abstract and citation databases of peer-reviewed research literature were used. The time period selected was from inception to March 2024. For a thorough outlook of the current research landscape, only original research articles were included in the scientometric analysis. Conference papers, reviews, and proceeding papers were excluded from the analysis. Selected keywords encompassing the concepts of "age estimation", "dental" and "artificial intelligence" were used for the bibliographical search as detailed in Table 1. The keywords were searched within the "Article Title, Abstract, Keywords" (SCOPUS) and "Topic" (WoS) domain to ensure all relevant publications were included and were not overlooked. Upon keyword search 78 articles were identified from SCOPUS database whilst 62 articles were identified from WoS. Manual screening was conducted by authors MZZ and AA to ensure all articles were related to DAE and AI. 8 articles were excluded as they did not conform to DAE studies. 132 articles were included in the final raw bibliography dataset.

2.2 Pre-Processing

Pre-processing of the databases was conducted to consolidate and merge information from both databases. Two separate pre-processing steps were conducted on the datasets, one with the duplicates removed and one without removing study duplicates. The pre-processing step without removing the study duplicates was conducted to measure publication trends in both separate databases. Other bibliometric analysis were conducted using the pre-processing step with the study duplicates removed to ensure unbiased data analysis. Without removing of duplicates, a total of 132 research articles were loaded into ScientoPy for analysis. 56.80% of the articles were obtained from SCOPUS while 43.20% were retrieved from WoS. The duplication removal analysis indicated that 54 article duplicates (40.90%) were found when both databases were merged. These articles were subsequently removed for further analysis. A total of 78 articles were left after removal of duplicates. These 78 articles were analysed for the scientometric parameters of interest. The identification and elimination of duplicate entries ensures accurate and reliable bibliometric analyses from here onwards. Figure 1 shows a flowchart of the dataset collection and selection.

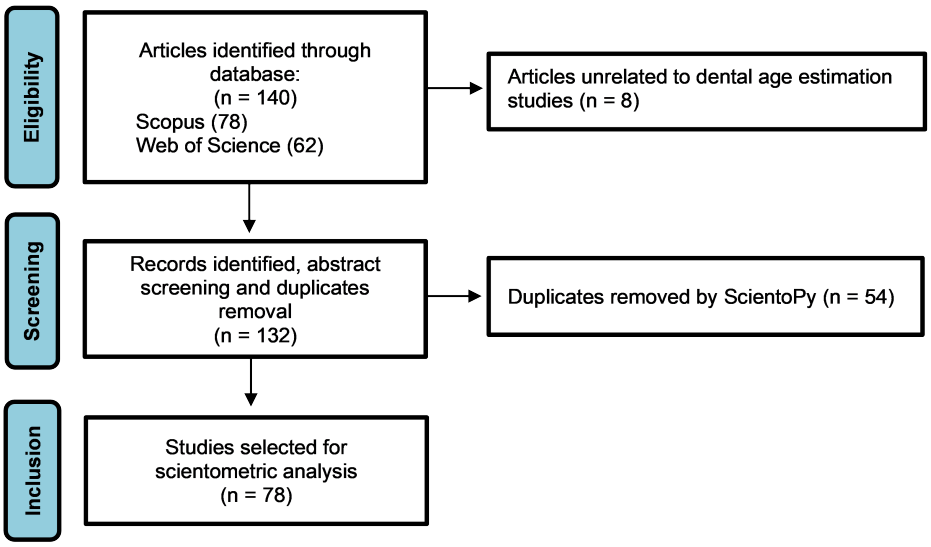

Figure 1: An evaluation process of article selection.

3 Results and Discussion

3.1 Publication Trend in AI-driven DAE Research

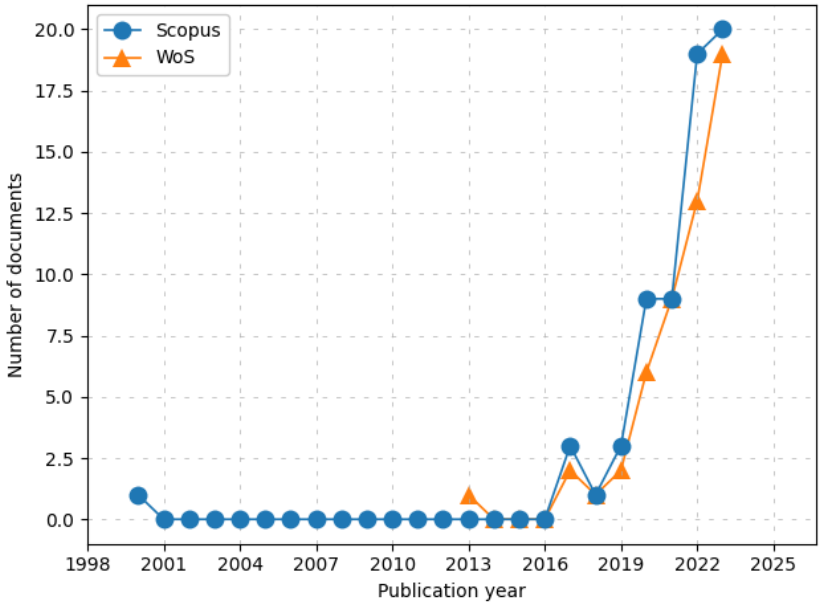

Figure 2: Trends in the number of publications on AI-driven DAE studies (1998-2023)

Figure 2 presents a comparison between the WoS and SCOPUS databases regarding the total number of publications concerning AI-driven DAE research across time, since inception to 2023. Publications in 2024 were not included as the year is still ongoing. Up to 2023, WoS publications has an Average Growth Rate (AGR) of 5.0, whilst SCOPUS has an AGR of 5.5, indicating a strong increase in the growth rate

of publications in recent years for both databases. The Publication Density per Last Year (PDLY) for both WoS and SCOPUS were 60.4 and 60.0 respectively, implying that roughly more than half of the total publications were produced between years 2021-2023. The H-index for WoS is 13, indicating that 13 publications have each received at least 13 citation whilst the H-index for SCOPUS is 16.

3.2 Top Countries and Research Institutions in AI-driven DAE Research

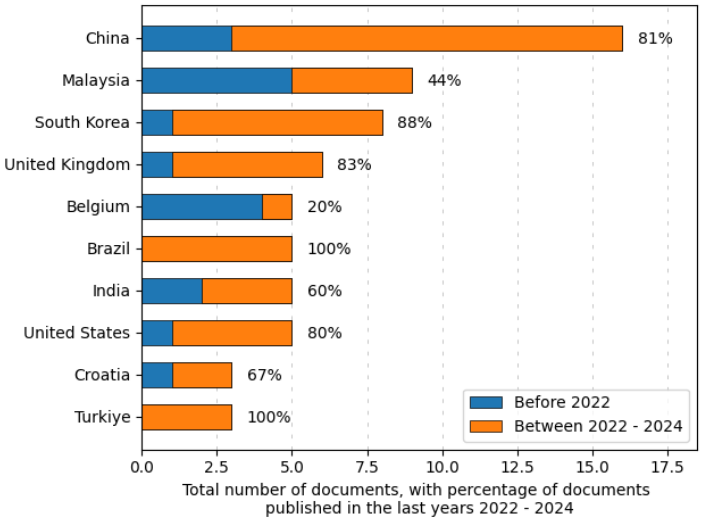

Figure 3: Top leading countries on AI-driven DAE studies (1998-2024)

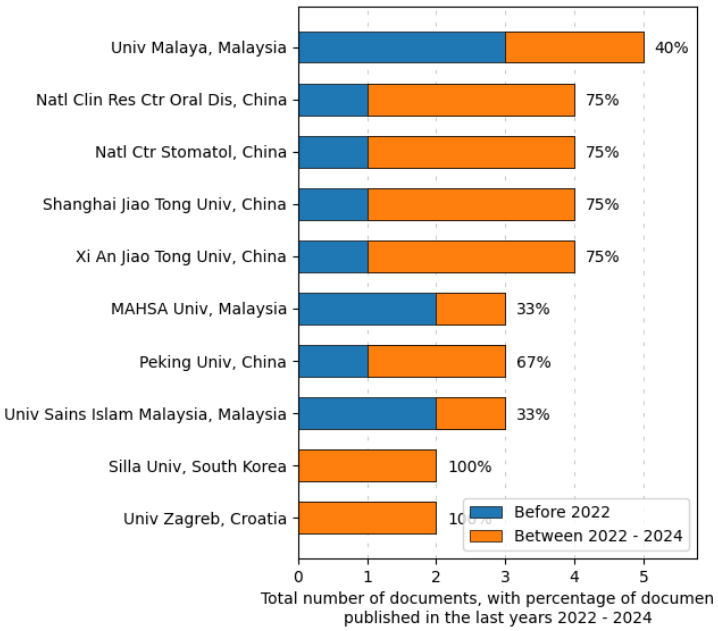

Figure 4: Top leading research institutions on AI-driven DAE studies (1998-2024)

Figure 3 and Figure 4 provides insights into the number of publications of different countries and research institutions incorporating AI methods in DAE studies from inception to 2024. China takes the lead with the highest number of publications (16 publications) in incorporating AI in DAE studies. This is unsurprising as China is also leading the world in incorporating AI in other areas as well such as in higher education [15], elderly healthcare [16], as well as AI governance [17]. Following China is Malaysia is in second position with 9 publications, and South Korea with 8 publications, showcasing these Asian countries efforts to be at the forefront of global research. These Asian countries are followed by United Kingdom (6 publications), Belgium (5 publications), Brazil (5 publications), India (5 publications), United States (5 publications), Croatia (3 publications) and Turkiye (3 publications) respectively.

According to a previous bibliometric study, these countries, excluding Malaysia, South Korea and Croatia, already have a strong background in DAE research [18]. These countries have demonstrated a strong interest in refining and advancing dental age estimation methodologies studies within their own populations. It is natural for them to incorporate AI techniques into their established DAE work to further improve their age estimation methods. Malaysia, South Korea and Croatia are however not without their own merit. Though not being included in the top 10 list of countries publishing in dental age estimation research in general, they do have strong involvement in dental age estimation studies [19, 20, 21]. Their initiative to incorporate AI methods in their studies shows their efforts to contribute to the novel area of study. Furthermore, based on the generated data in Figure 3, it can be seen that countries have mostly produced publications on AI-driven DAE from 2022 and has steadily increased in the following year. As age estimation is a population-specific field of study, it is an encouraging trend that countries all over the globe are refining age estimation methods within their own populations.

Referring to research institutions that are active in AI-driven DAE research in Table 4, the list of institutions corresponds to the list of top 10 countries. China is represented by 5 institutions (National Clinical Research Center for Oral Diseases, National Center for Stomatology, Shanghai Jiao Tong University, Xi'an Jiaotong University and Peking University), Malaysia is represented by 2 institutions (Universiti Malaya and MAHSA University), whilst South Korea and Croatia are each represented by one institution each, Silla University and University of Zagreb respectively. The top 10 research institutions imply that these institutions possess expertise and resources in dental age estimation studies, as well as expertise in artificial intelligence and machine learning. Another interesting aspect to note is the geographic distribution of the top institutions. The list comprises of establishments from such as Europe, Asia, and the Americas. This diversity reflects the global interest in dental age estimation research and the participation of researchers from diverse populations.

3.3 Top Journals Publishing AI-driven DAE Research

Table 2 displays the top 10 journals publishing studies on AI-driven DAE. Based on the list, it can be observed that the journals accepting publications on AI-driven DAE studies are from diverse areas of studies ranging from journals on legal medicine, oral health, computational studies and forensic studies. This indicates that future authors have a wide range of journals to select from when it comes to publishing AI-driven DAE studies. Leading the list with 9 publications is the International Journal of Legal Medicine whose scope focuses on clinical forensic pathology, forensic haemogenetics, forensic toxicology, and traffic medicine. Jointly with 4 publications each is BMC Oral Health and Scientific Reports. BMC Oral Health a well-known journal in the field of dentistry and oral health whose publications focuses on articles covering the aspects of prevention, diagnosis and management of disorders of the mouth, teeth and gums, as well as related molecular genetics, pathophysiology, and epidemiology. Scientific Reports on the other hand is a more general journal which covers all areas of the natural sciences, psychology, medicine and engineering. All the 3 journals are under the SpringerNature company which has nearly 200-year track record of publishing trusted scientific research.

Table 2: Top Journals Publishing AI-driven DAE Research

Pos.	Source Title	Total	Publisher	CiteScore 2022	SJR 2022	SNIP 2022
1	International Journal of Legal Medicine	9	Springer Nature	5.1	0.792	1.158
2	BMC Oral Health	4	Springer Nature	4.1	0.741	1.368
3	Scientific Reports	4	Springer Nature	7.5	0.973	1.312
4	Computers Materials & Continua	3	Tech Science Press	5.0	0.525	1.080
5	Egyptian Journal of Forensic Sciences	3	Springer Nature	1.8	0.357	1.248
6	Forensic Science International	3	Elsevier	4.8	0.740	1.180
7	Australian Journal of Forensic Sciences	2	Taylor & Francis	2.9	0.392	0.610
8	Journal Of Forensic Sciences	2	Wiley-Blackwell	3.4	0.607	0.931
9	Legal Medicine	2	Elsevier	2.5	0.512	0.814
10	Multimedia Tools and Applications	2	Springer Nature	6.1	0.720	1.182

3.4 Top Most Cited Articles in AI-driven DAE Research

Table 3 displays the top 10 most cited articles in AI-driven DAE research. An analysis of the most cited papers provides an overview of the articles mostly referred to in AI-driven DAE research. These studies indirectly pioneer AI-driven DAE research as they provide a platform for future studies to build upon.

The study by Vila-Blanco N. et al., published in 2020 sits at the front with 56 citations [22]. This study discusses a novel deep learning approach to chronological age estimation based on orthopantomogram (OPG) images. The authors argued that conventional chronological age estimation relied on manual measurements and that requires time and effort. The authors also states that as the measurements were conducted manually, a high degree of subjectivity between intra- and inter-observer existed when conducting dental evaluations. As a solution, to improve age estimation methods in terms of time and subjectivity, the authors proposed a deep learning approach that is completely automatic, uses raw OPG images without any preprocessing, and does not require dental measurements or other manual annotations to obtain accurate results. In this study, the novel deep learning approaches were carried out using Convulational Neural Networks (CNN) which capability had already been established in analysing medical images at the time of the study. The two different network architectures used in the study, respectively named DANet (Dental Age Net) and DASNet (Dental Age and Sex Net), were developed using the Keras toolkit. DANet, focused on estimating age, consists of a single path where convolution and pooling layers were interleaved to learn image features at different scales. The second network architecture, DASNet, adds a second path which is identical to the first, aimed at estimating sex. The authors claim that to the best of their knowledge, this study is the first to use deep learning techniques for automatic calculation of chronological age from OPG images. Due to this, it is unsurprising that this publication has been highly cited and referenced, and has been a precursor for future AI-driven dental age estiomation studies.

At second place is the study by Stern D. et al. published in 2019 with 47 citations, which proposed a novel method for MRI-based fully automatic multi-factorial age estimation from three anatomical sites on a dataset of 322 subjects in the age range of 13 and 25 years [23]. In this study, the authors argue that chronological age estimation is prone to uncertainties due to biological variation amongst subjects

Table 3: Top 10 Cited Articles on AI-driven DAE Research

No.	Authors	Title	Year	Source Title	Citations
1	Vila-Blanco, N., Carreira, M.J., Varas-Quintana, P., Balsa-Castro, C., Tomas, I.	Deep Neural Networks for Chronological Age Estimation From OPG Images	2020	IEEE Transactions On Medical Imaging	56
2	Stern D., Payer C., Giuliani N., Urschler M.	Automatic Age Estimation and Majority Age Classification from Multi-Factorial MRI Data	2019	IEEE Journal of Biomedical and Health Informatics	47
3	Kim, S., Lee, Y.H., Noh, Y.K., Park, F.C., Auh, Q.S.	Age-group determination of living individuals using first molar images based on artificial intelligence	2021	Scientific Reports	42
4	Farhadian, M., Salemi, F., Saati, S., Nafisi, N.	Dental age estimation using the pulp-to-tooth ratio in canines by neural networks	2019	Imaging Science In Dentistry	36
5	Stepanovsky, M., Ibrova, A., Buk, Z., Veleminska, J.	Novel age estimation model based on development of permanent teeth compared with classical approach and other modern data mining methods	2017	Forensic Science International	34
6	De Tobel J., Radesh P., Vandermeulen D., Thevissen P.W.	An automated technique to stage lower third molar development on panoramic radiographs for age estimation: a pilot study	2017	The Journal of Forensic Odonto-Stomatology	33
7	Guo, Y.C., Han, M.Q., Chi, Y.T., Long, H., Zhang, D., Yang, J., Yang, Y., Chen, T., Du, S.Y.	Accurate age classification using manual method and deep convolutional neural network based on orthopantomogram images	2021	International Journal Of Legal Medicine	32
8	Banar N., Bertels J., Laurent F., Boedi R.M., De Tobel J., Thevissen P., Vandermeulen D.	Towards fully automated third molar development staging in panoramic radiographs	2020	International Journal Of Legal Medicine	32
9	Boedi, R.M., Banar, N., De Tobel, J., Bertels, J., Vandermeulen, D., Thevissen, P.W.	Effect of Lower Third Molar Segmentations on Automated Tooth Development Staging using a Convolutional Neural Network	2020	Journal Of Forensic Sciences	31
10	Milosevic, D., Vodanovic, M., Galic, I., Subasic, M.	Automated estimation of chronological age from panoramic dental X-ray images using deep learning	2022	Expert Systems With Applications	30

with the same chronological age. Due to this, they opted for a multi-factorial age estimation method, making use of three anatomical sites, namely the bones of hands, clavicle and teeth. Similar to the study conducted by Vila-Blanco N. et. al., Stern D. et al. were also in favour of automatic age estimation methods as it would lessen the drawback of intra- and inter-rater variability. In their study they performed a multi-factorial age estimation using Deep Convulational Neural Networks (DCNN) which is based on mapping age-related information from the subjects hand, clavicle and wisdom teeths. The authors claim that their study is the first to provide a comprehensive evaluation of an automatic approach for information fusion from different anatomical sites for forensic purposes. Their study shows that an automated approach makes it possible for a multi-factorial age estimation method, with a prediction error of 1.01 $\pm$ 0.74 years, outperforming age estimation results solely derived from hand, clavicle and wisdom teeth individually.

At third place is the 2021 study by Kim S. et. al. with 42 citatitons. Kim S. et. al. proposed a novel deep learning system that provides a fully automated model for age-group determination using panoramic radiographs of the first molar [24]. The authors claim to the best of their knowledge, at the time of study, this was the first CNN-based dental age estimation based on images of the first molar. Moreover, through heat map visualisation via the application of a gradient-weighted class activation mapping (Grad-CAM) algorithm, the authors were able to visualise the information gathered, and recognise tooth and alveolar bone regions in the X-ray image in different age groups. The visual investigation using Grad-CAM reveals that CNNs learn a set of age-related holistic features and find important features in the shape of the target tooth. In addition, the Grad-CAM visualization also shows that CNNs trained with different age-group resolutions learn to not necessarily use the same visual features on identical teeth. The boosted performance in ensemble experiments in this study, supports the fact that CNNs learn diverse information from different images of interest, and varying the age-group resolution leads CNNs to learn partially independent information across different age-group resolution. The authors claim two properties of CNNs in order to predict the age groups of teeth: (1) CNNs learn different features from each individual tooth, and (2) CNNs learn different features from the same tooth depending on the age grouping used for learning.

By analysing the top 3 cited publications in AI-driven DAE studies, we could appreciate the diversity and potential application of AI methodologies in advancing DAE research. The highly cited publications have significantly advanced the fields of AI-driven DAE research. Their methodologies, analysis and insights continue to be instrumental in paving the road for AI-driven forensic investigations and bio-anthropology. Researchers and practitioners build upon these foundational works to improve age estimation techniques and deepen our understanding of ageing processes. Their impact is felt across disciplines and contributes to our knowledge of age-related phenomena.

3.5 Index-based Keyword Content Analysis

An analysis of keyword selection provides insights into the emerging directions and expanding scope of AI-driven DAE studies. Tracking keyword patterns across successive publications reveals the changing priorities and interests of investigators across time. Keyword trend analysis also highlights research gaps yet to be explored by future studies, thereby motivating forthcoming efforts to address such voids. Using VOSviewer, a bibliometric network analysis tool, indexed keywords from the 78 publications of interest were analysed. As the area of AI in DAE is relatively new and recent, keywords with a threshold of at least 10 occurrences for the inclusion of terms. Of the 555 terms extracted, 25 terms crossed the threshold criteria.

Co-occurrence network mapping was conducted on these 25 keywords in VOSviewer to identify clusters and connections between the published articles. Co-occurrence analysis allows discernment of both established and emerging topics by weighing frequent keywords as well as rising terms. The visual map in Figure 5, provides an overview of the landscape of indexed keywords most commonly associated with AI-driven DAE since its inception. Index keywords, instead of author keywords, were chosen for analysis

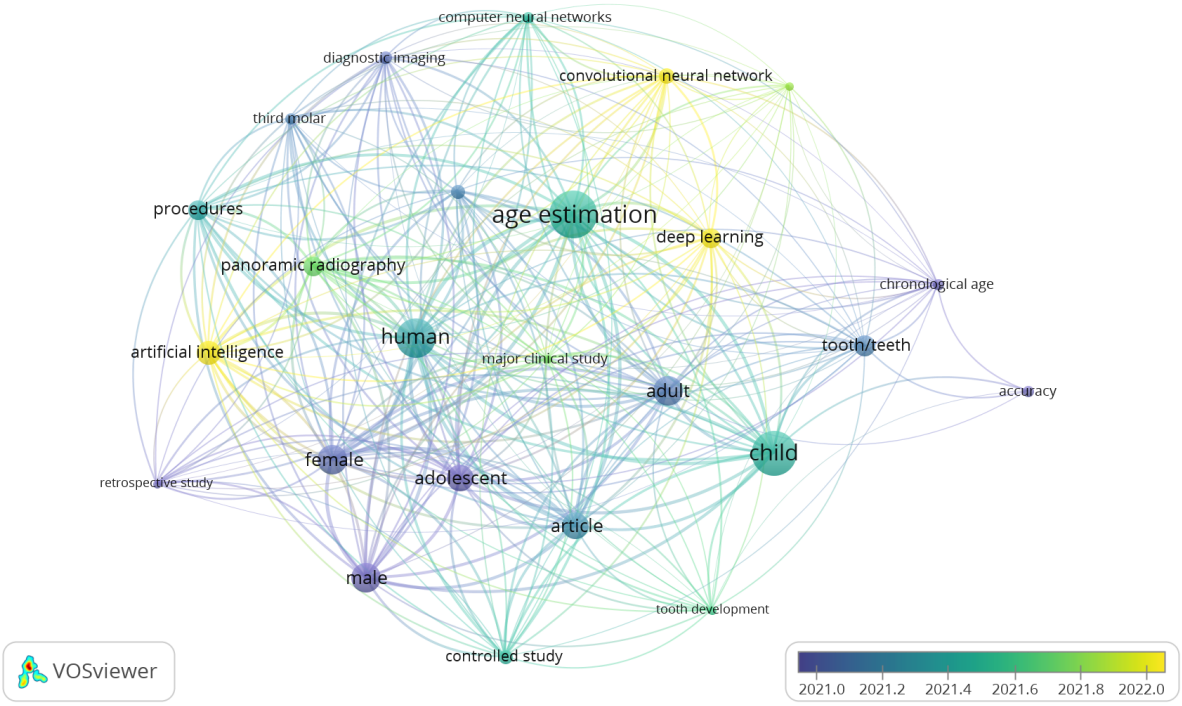

Figure 5: Overlay network map of citations by index keywords.

as they pool words and/or phrases used to describe a specific concept, instead of analysing the variety of keywords chosen by independent authors that may refer to the same concept.

In this analysis, the size of the label and the circle of an item is determined by the weight of the item. The higher the weight of an item, the larger the label and the circle of the item. Lines between items represent links. The distance between two keywords in the visualization approximately indicates the relatedness of the keywords in terms of co-citation links. In general, the closer two keywords are located to each other, the stronger their relatedness. In this Overlay Network map of index keywords, the colour of the item indicates the year the keyword appears in. The darker shade (purple) represents keyword appearance in the year 2020, whilst the light shade (bright yellow) represents keywords that has appeared at a much more recent year. The colour bar indicator at the bottom right corner represents years 2020-2023 as the 78 articles chosen for analysis were published within these years.

Notably, keywords representing “age estimation” and keywords that represent sex (“male” and “female”) and age specific groups (“child”, “adolescent” and “adult”) are in darker shades of colour as age estimation studies focusing on sex and age groups have existed before the introduction of AI, using traditional methods. Keywords under the umbrella of “artificial intelligence”, “deep learning” and “convolutional neural network” are in brighter shades of yellow as they have appeared much more recently in time and are gaining attention in todays research niches. Other keywords such as “tooth development”, “third molar”, “demirjian” and “maturity” represents the characteristics or parameter chosen to estimate dental age.

Overall, the keyword analysis underscores the variety of keywords, scopes and niche areas that are significant to dental age estimation studies. The high occurrences of these keywords highlight the variety and relevance of methods research groups are undertaking in order to achieve reliable and accurate age determination techniques.

4 Conclusion

DAE studies have been on the rise in the last decades due to their importance in forensic investigations as well as bioanthropology studies. In the past few years, researchers have attempted to increase its reliability and accuracy via AI and machine learning. A scientometric analysis of the application of AI in DAE studies outlines the trend in number of publications, prolific countries and research institutions, publishing journals, highly cited publications and frequent keywords in the area of AI in DAE. However, as the niche area of integrating AI and DAE is fairly recent, a limitation of this study is that its sample size does not exceed the 100-300 number of analysed studies of other scientometric studies. Nevertheless, this factor does not undermine the importance of scientometric analysis and interpretation. Scientometric analyses provide a birdseye overview of the current research trend and provide a glimpse of future research opportunities to come in the future. Literature analysis via scientometric studies may aid in identifying research gaps and opportunities, and further enhance DAE accuracy and applicability in dental forensic research.

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Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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