Imaging Science in Dentistry 2023; 53: 91-9
https://doi.org/10.5624/isd.20221226

Dental age estimation using cone-beam computed tomography: A systematic review and meta-analysis

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ABSTRACT

Purpose: This systematic review aimed to investigate the correlation between chronological age and dental pulp volume in cone-beam computed tomography (CBCT).

Materials and Methods: The literature was searched in 4 databases (PubMed, Scopus, Web of Science, and Google Scholar). Within each study, the outcome of interest was the correlation (r) between chronological age and pulp volume. A random-effect meta-analysis was conducted. Subgroup analysis was carried out according to sex and tooth type.

Results: Of 5,693 identified studies, 27 fulfilled the inclusion criteria and were selected for meta-analysis. These articles focused on single-rooted teeth (n = 21), multi-rooted teeth (n = 6), maxillary teeth (n = 14), mandibular teeth (n = 6), and maxillary and mandibular teeth (n = 12). The relationship between chronological age and dental pulp volume was examined in the entire population (r = −0.67), men (r = −0.75), and women (r = −0.77) in single- and multi-rooted teeth. The results of the total population analysis showed a relatively strong negative relationship between age and pulp volume.

Conclusion: This study suggested that CBCT is a reliable and repeatable tool for dental age estimation. A strong inverse relationship was observed between pulp chamber volume and age. Further studies on the correlation between chronological age and pulp volume of multi-rooted teeth may be beneficial. ***(Imaging Sci Dent 2023; 53: 91-9)***

KEY WORDS: Cone-Beam Computed Tomography; Systematic Review; Age Determination by Teeth; Statistics

Introduction

Dental age estimation (DAE) has major applications in a variety of sciences, including anthropology, archeology, medicine, and clinical and forensic dentistry. DAE in forensic dentistry is considered an important criterion for identifying corpses. It also provides useful information for the diagnosis, treatment plan, and prognosis in clinical dentistry, especially pediatric dentistry and orthodontics.[1]

In general, dental age is estimated by teeth and skeletal structures. DAE based on teeth is preferred over DAE based on skeletal structures, as the former is considered the hardest tissue of the body and is naturally resistant to a variety of chemical-mechanical damage and corrosion. Teeth remain intact and healthy even when other skeletal structures disintegrate[1] and are less affected by environmental, nutritional, and genetic factors than other body organs.[2]

Age is estimated based on the tooth eruption sequence and tooth development stage up to 24 years, while DAE based on teeth in adulthood (i.e., after third molar development) remains a matter of debate due to the completion of the tooth development stages, and DAE in adults is mainly based on degenerative dental changes.[3]

Numerous adult DAE methods have been developed based on measurements of pulp chamber volume reduction.[3] Most of these methods are invasive, requiring the extraction of damaged teeth, for which reason they are not suitable

Received December 26, 2022; Revised January 16, 2023; Accepted January 25, 2023
Published online February 11, 2023
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Imaging Science in Dentistry · pISSN 2233-7822 eISSN 2233-7830

for living individuals.[3]

Reduced pulp chamber volume resulting from secondary dentin deposition can be calculated using histology, biochemical, and radiographic techniques. While histology and biological techniques are time-consuming and require special laboratory conditions, radiographic techniques are less invasive and do not necessitate tooth extraction. Other advantages of radiographic techniques include the ability to make measurements without damaging the dental structure, unlike histology techniques, being faster and simpler than biological techniques, and their applicability to teeth in both living and dead individuals.[2]

Numerous radiographic techniques have been employed to measure the reduction in pulp chamber volume in adults. For example, cone-beam computed tomography (CBCT) enables sagittal, coronal, and axial images to be captured, providing dentists with useful information about the tooth structure. To this end, many studies have analyzed CBCT scans obtained for diagnostic purposes to measure the relationship between pulp volume and patient age.

Numerous studies have been conducted on age estimation, but they have yielded different results. Some have reported that the pulp-to-tooth volume ratio had a relatively high ability to serve as an indicator for age estimation, while others have reported a weaker relationship. Accordingly, this systematic review aimed to evaluate the ability of the pulp-to-tooth volume ratio from CBCT scans to predict DAE.

Materials and Methods

This systematic review (registered with the Research Council of the Hamadan University of Medical Sciences with the ethics code of IR.UMSHA.REC.1400.471) was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) checklist.[4]

Eligibility criteria

The population, intervention, comparison, and outcome (PICO) framework was applied to define eligibility criteria. The population was patients aged between 10 and 80 years who had high-quality and artifact-free CBCT, intact anterior or posterior teeth, and no caries or extensive restorations. The intervention, which is referred to as the predictor in observational studies, was the pulp-to-tooth ratio. The comparison category was not applicable in this study, and the outcome was patients' age (in years). Studies using other imaging techniques such as panoramic radiography, magnetic resonance imaging (MRI), micro-computed tomography (micro-CT), and periapical radiography were excluded. Failure to report correlation coefficients (r) also led to exclusion.

Information sources

The MEDLINE/PubMed, Scopus, Web of Science, and Google Scholar databases were searched until May 6, 2021. A manual search was performed to find more articles in the reference lists of selected articles. A limited search was also conducted on the websites of related conferences held in the last 5 years. Most of the posters presented at these conferences did not contain the full text; thus, their authors were contacted via email to obtain the full text.

Search strategy

For each database, a separate search strategy was created. The search was conducted using main keywords (CBCT, dental age estimation, pulp/tooth ratio) and their synonyms. In PubMed, the database search was conducted according to Medical Subject Headings (MeSH), in Scopus according to

Table 1. Search strategy used in each database

Database	Search strategy
Scopus	(Title/Abstract/Key word (cone beam ct OR CBCT OR cone_beam ct OR cone beam computed tomography)) AND (Title/Abstract/Key word (age estimation OR dental age)) AND (Title/Abstract/Key word (pulp/teeth ratio OR volumetric analysis OR dental volume))
PubMed	(((((cone beam computed tomography[MeSH Terms]) AND (age estimation[Title/Abstract])) OR (dental age[Title/Abstract])) AND (pulp teeth ratio[Title/Abstract])) OR (volumetric analysis[Title/Abstract])) OR (dental volume[Title/Abstract])
Web of Science	(TS = "cone beam ct" OR TS = "cone_beam ct" OR TS = "cbct" OR TS = "cone beam computed tomography") AND (TS = age estimation OR TI = dental age) AND (TS = " pulp teeth ratio" OR TS = "dental volume" OR TS = "volumetric analysis")
Google Scholar	((cone beam ct OR cone_beam ct OR cbct OR cone beam computed tomography) AND (age estimation OR dental age) AND (pulp teeth ratio OR volumetric analysis OR dental volume))

Table 2. Details of the included studies

Studies	Country	Application	Sample size	r	Age
Akay et al. (2017)[2]	Turkey	ITK-SNAP 3.4.0	134	−0.544	16-77
Biuki et al. (2017)[3]	Iran	Mimics	76	0	13/6-69/54
Asif et al. (2018)[11]	Malaysia	3D-Doctor	131	−0.486	17-75
Uğur Aydin et al. (2019)[12]	Turkey	OnDemand	135	−0.515	18-63
De Angelis et al. (2015)[13]	Italy	Computer-compatible cone-beam CT software	155	−0.361	18-58
Doni et al. (2021)[14]	India	ITK-SNAP 3.4.0	116	−0.881	
Elgazzar et al. (2020)[15]	Egypt	Mimics	110	−0.799	16-65
Ge et al. (2015)[16]	China	InVivo5	120	−0.615	14-75
Ge et al. (2016)[17]	China	Osiri X	91	−0.624	17-80
Gulsahi et al. (2018)[18]	Turkey	Advantage Windows workstation	140	−0.63	10-70
Jagannathan et al. (2011)[19]	India	OnDemand 3D	124	−0.769	20-77
Kazmi et al. (2019)[20]	Pakistan	ITK-SNAP 3.4.0	81	−0.648	15-71
Lee et al. (2017)[21]	South Korea	OnDemand 3D	148	−0.761	10-80
Marroquin et al. (2018)[22]	Australia	OnDemand	300	−0.779	14-60
Molina et al. (2021)[23]	Spain	OnDemand	111	−0.583	10-65
Nemsi et al. (2017)[24]	Tunisia	ITK-SNAP 3.4.0	372	−0.75	
Al-Omoush et al. (2021)[7]	Jordan	Itk-snap	90	−0.985	6-50
Oscandar et al. (2018)[25]	Indonesia	I-Cat workstation	60	−0.545	22-70
Pinchi et al. (2015)[26]	Italy	Mimics	300	−0.83	16-65
Porto et al. (2015)[27]	Brazil	OnDemand	100	−0.94	
Salemi et al. (2020)[28]	Iran	ITK-SNAP 3.4.0	200	−0.96	15-60
Star et al. (2011)[29]	Belgium	3D-Doctor	204	−0.391	>15
Sue et al. (2018)[30]	Japan	Planmeca Romexis	717	−0.509	15-65
Adisen et al. (2018)[6]	Turkey	Planmeca Romexis	107	−0.167	14-70
Alsoleihat et al. (2017)[8]	Jordan	CBCT software	87	−0.78	11-74
Andrade et al. (2019)[9]	Brazil	ITK-SNAP 3.4.0	116	−0.39	13-70
Asif et al. (2019)[10]	Malaysia	Mimics	300	−0.24	16-65

Title/Abstract keywords, and in Web of Science according to topic (Table 1).

The search process was performed by 2 authors separately, and the selected articles were imported into EndNote 20 (Thomson Reuters, Toronto, Canada). In the next step, the 2 authors removed duplicate articles selected in the first step by reading the titles of the articles. After removing irrelevant articles in the second step, the 2 authors read the abstracts and removed additional irrelevant articles. Finally, they proceeded to read the full text of the remaining articles. After removing those that did not satisfy the eligibility criteria, data were collected from the remaining articles. In cases of disagreement, they consulted with a third party, and the selection process was finalized.

Data items

Information to answer the research question was extracted from the articles independently by the 2 authors. The following information was entered into the information extraction form (Table 2) when the 2 authors reached an agreement: first author name and year of publication, country, the application used in the study, sex, sample size, age range, r (correlation coefficient), and the type of teeth observed. In cases of disagreement, the authors consulted with a third party.

If information was missing, an email was sent to the article's corresponding author. If they did not respond, the article was excluded.

Study risk of bias assessment

The quality of articles was measured using the Newcastle-Ottawa Scale[5] (Table 3). This checklist is a tool for measuring the quality of systematic reviews and meta-analyses and consists of 8 sections classified into 3 groups: the selection of the study groups; the comparability of the groups; and the ascertainment of either the exposure or outcome of inter-

Table 3. Assessment of risk of bias in the included studies using the Newcastle-Ottawa checklist

Studies	Representativeness of sample	Selection of control group	Ascertainment of exposure	None-respondent	Comparability	Assessment of outcome	Statistical test
Adisen et al. (2018)[6]			**	*	**	**	*
Akay et al. (2017)[2]			**	*	**	**	*
Al-Omoush et al. (2021)[7]	*		**	*	*	**	*
Alsoleihat et al. (2017)[8]	*		**	*	**	**	*
Andrade et al. (2019)[9]			**	*	**	**	*
Asif et al. (2018)[11]			**	*	**	**	*
Uğur Aydin et al. (2019)[12]	*		**	*	**	**	*
De Angelis et al. (2015)[13]			**	*	**	**	*
Jagannathan et al. (2011)[19]			**	*	**	**	*
Lee et al. (2017)[21]			**	*	**	**	*
Marroquin et al. (2018)[22]			**	*	**	**	*
Pinchi et al. (2015)[26]			**	*	**	**	*
Salemi et al. (2020)[28]			**	*	**	**	*
Star et al. (2011)[29]			**	*	**	**	*
Ge et al. (2015)[16]			**	*	**	**	*
Biuki et al. (2017)[3]			**	*	**	**	*
Oscandar et al. (2018)[25]			**	*	*	**	
Porto et al. (2015)[27]			**	*	**	**	*
Asif et al. (2019)[10]			**	*	**	**	*
Doni et al. (2021)[14]			**	*	*	**	*
Elgazzar et al. (2020)[15]			**	*	**	**	*
Ge et al. (2016)[17]			**	*	**	**	*
Gulsahi et al. (2018)[18]			**	*	**	**	
Kazmi et al. (2019)[20]			**	*	**	**	*
Molina et al. (2021)[23]			**	*	**	**	*
Sue et al. (2018)[30]			**	*	**	**	*
Nemsi et al. (2017)[24]			**	*	**	**	*

*: quality of studies assessed as the maximum (9-10 stars)

est for case-control or cohort studies. Stars are assigned to each quality item, and articles are categorized as follows: 9-10, very good; 7-8, good; 5-6, satisfactory; and 0-4, unsatisfactory.

The correlation coefficient was utilized as an effect measure with a 95% confidence interval. The inverse variance weighting method with a random-effect approach was used to combine the results from different studies. The I^2 statistic was also used to determine heterogeneity. The Comprehensive Meta-Analysis software was also employed. Subgroup analyses were carried out according to sex and tooth type. The Begg test was used to assess reporting bias, with a *P*-value of less than 0.05 indicating the presence of reporting bias. Measurements are reported with 95% confidence intervals.

Results

Searching the 4 databases yielded 5,693 articles. After removing duplicate and irrelevant articles, 3,141 articles were selected for title review. After reading the titles, 2,902 articles were excluded because their titles were irrelevant to the topic of the study and 239 articles were selected for abstract review. Of those articles, 179 were removed because they failed to meet the inclusion criteria and were irrelevant. Finally, 60 articles were selected for full-text review. Some were removed because they used other imaging techniques such as MRI, panoramic radiography, periapical radiography, or micro-CT, some because they failed to report correlation coefficients, and others because they contained unclear information. Finally, 27 articles were selected for meta-analysis (Fig. 1).[2,3,6-30]

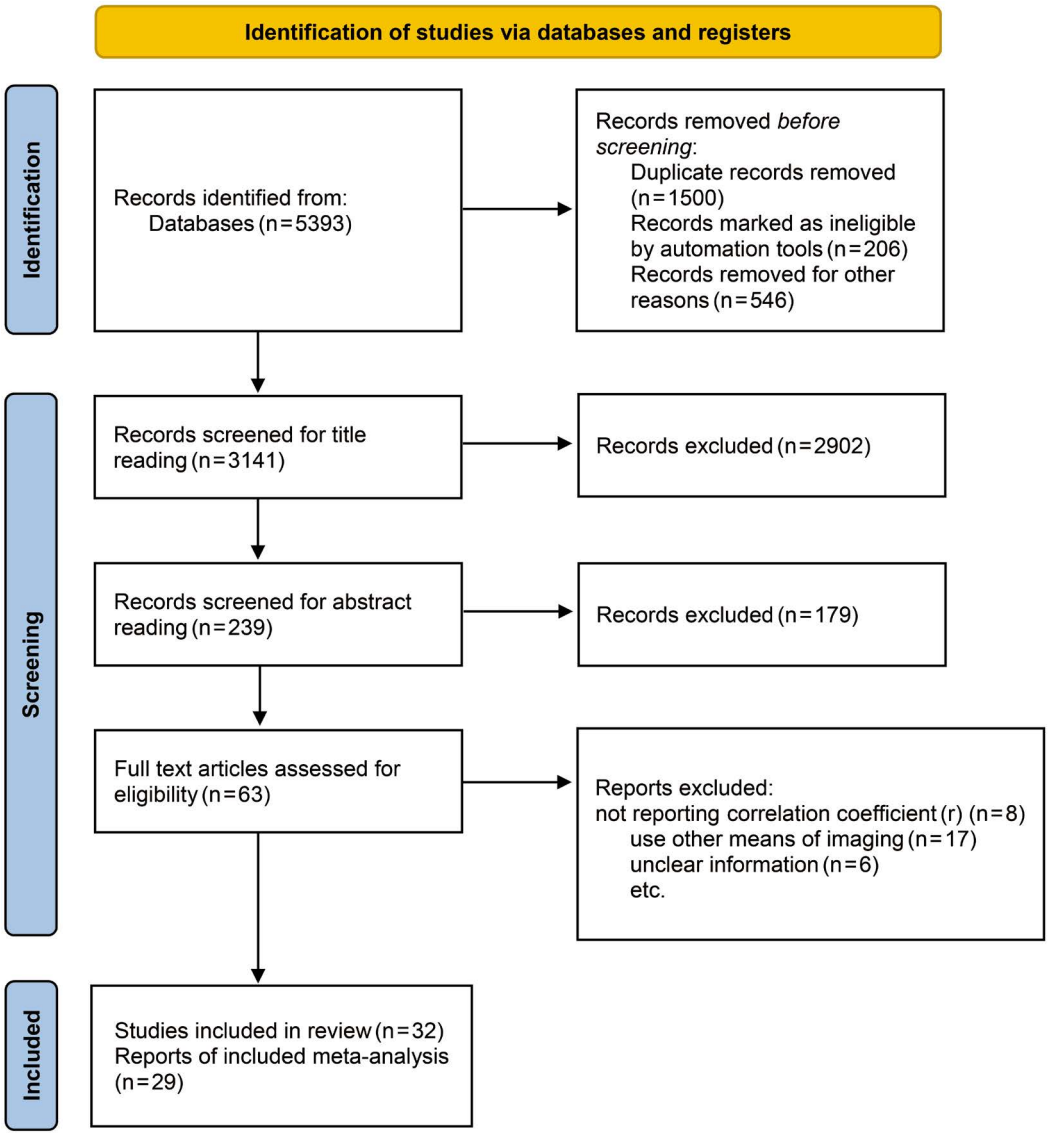

Fig. 1. PRISMA flowchart for the systematic review.

Table 2 summarizes the information extracted from the articles used in the review. These articles were published from 2011 to 2021. Among them, 18 articles focused on Asian populations (including Turkey, Jordan, Malaysia, Indonesia, Pakistan, Tunisia, Iran, South Korea, Japan, and China), 4 articles on European populations (including Italy, Spain and Belgium), 4 articles on South American populations, and 1 article on an African population. Among these articles, 21 focused on single-rooted teeth, 6 on multi-rooted teeth, 14 on maxillary teeth, 6 on mandibular teeth, and 12 on maxillary and mandibular teeth.

This study examined the relationship between chronological age and pulp volume in the entire population (including

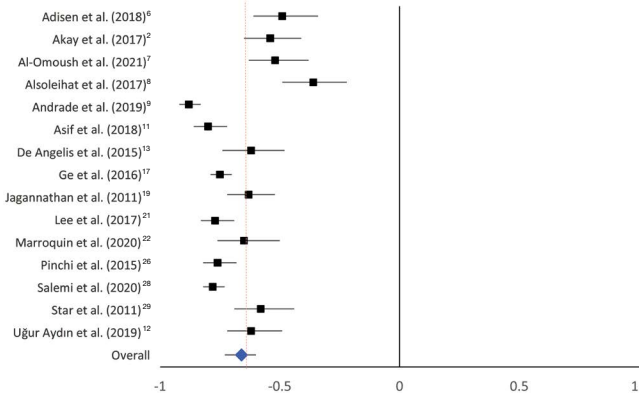

Fig. 2. Forest plot of the correlation between dental pulp volume and age.

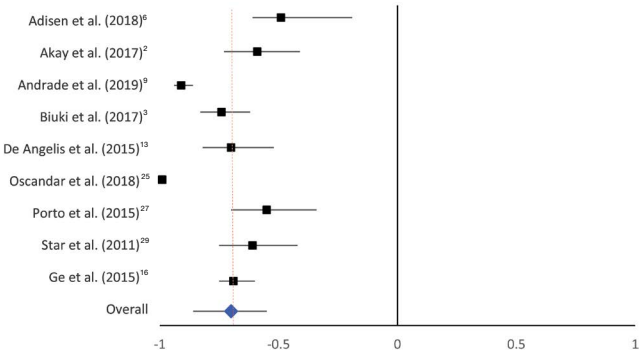

Fig. 3. Forest plot of the correlation between dental pulp volume and age in the female population.

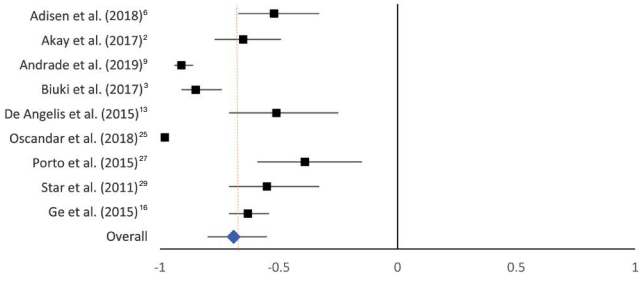

Fig. 4. Forest plot of the correlation between dental pulp volume and age in the male population.

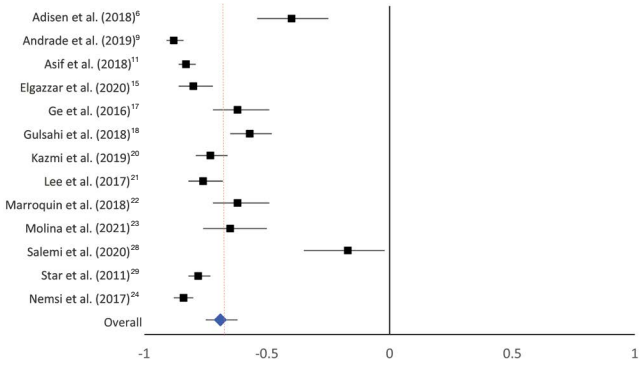

Fig. 5. Forest plot of the correlation between pulp volume and age in the maxillary central incisors.

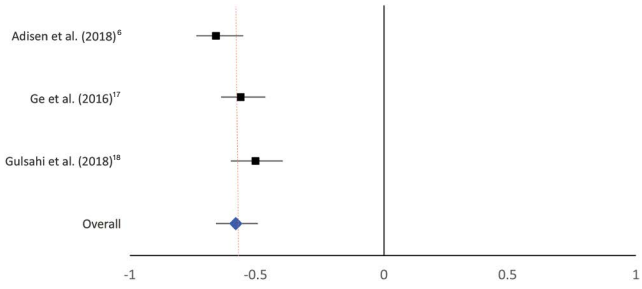

Fig. 6. Forest plot of the correlation between pulp volume and age in the maxillary lateral incisors.

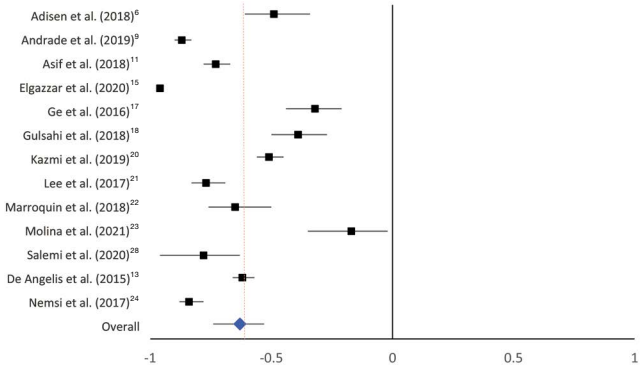

Fig. 7. Forest plot of the correlation between pulp volume and age in the maxillary canines.

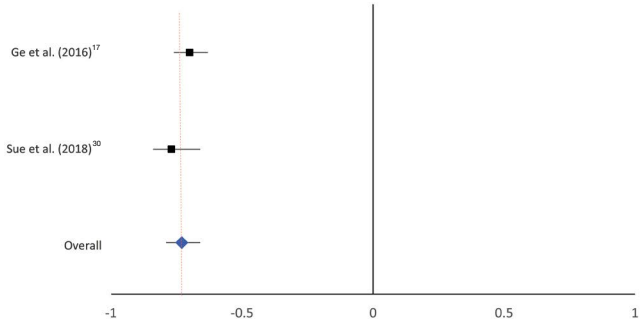

Fig. 8. Forest plot of the correlation between pulp volume and age in the mandibular lateral incisors.

men and women) in single- and multi-rooted teeth. The results of the total population analysis ($r = -0.67$) showed a relatively strong negative relationship between age and pulp volume (Fig. 2).

The results of the subgroup analysis by sex indicated that pulp volume was very closely correlated with age. The correlation coefficient was -0.75 for men and -0.77 for women (Figs. 3 and 4).

The correlation analysis by tooth type, as shown in Figures 5-15, indicated differences in the strength of the relationship between pulp volume and age. The strongest and weakest relationships were observed in the mandibular first molars ($r = -0.83$) and mandibular third molars ($r = -0.36$).

The Newcastle-Ottawa Scale was used to measure the quality and risk of bias of cross-sectional studies. According to the quality assessment results by this checklist, 3 studies were very good, 23 were good, and 1 was satisfactory (Table 3). The analysis of heterogeneity using the I^2 statistic showed

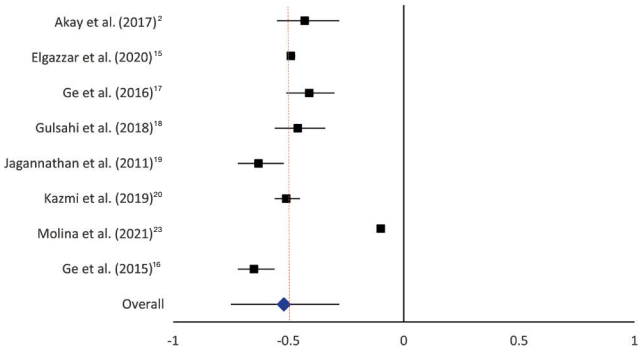

Fig. 9. Forest plot of the correlation between pulp volume and age in the mandibular canines.

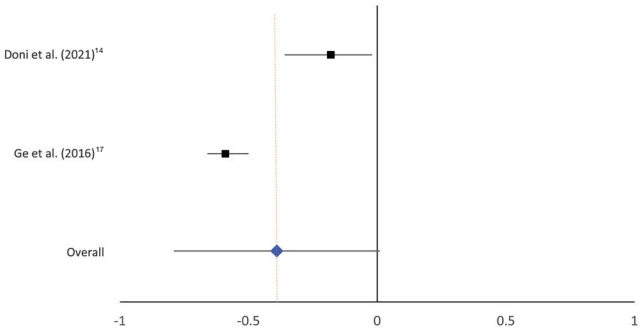

Fig. 10. Forest plot of the correlation between pulp volume and age in the mandibular second premolars.

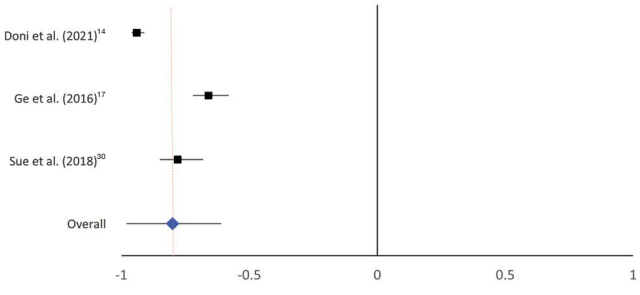

Fig. 11. Forest plot of the correlation between pulp volume and age in the mandibular first molars.

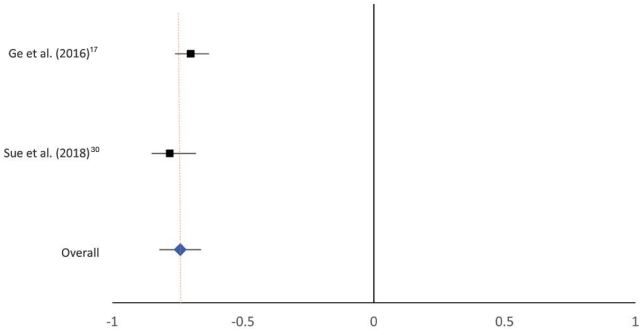

Fig. 12. Forest plot of the correlation between pulp volume and age in the mandibular second molars.

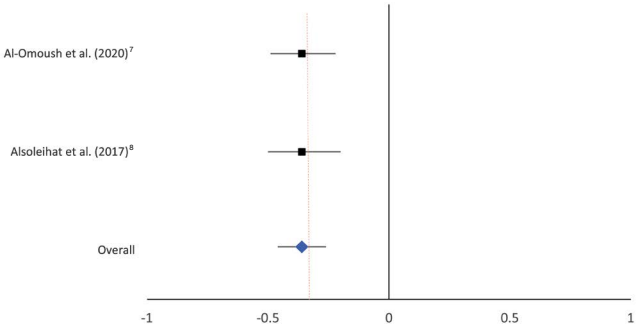

Fig. 13. Forest plot of the correlation between pulp volume and age in the mandibular third molars.

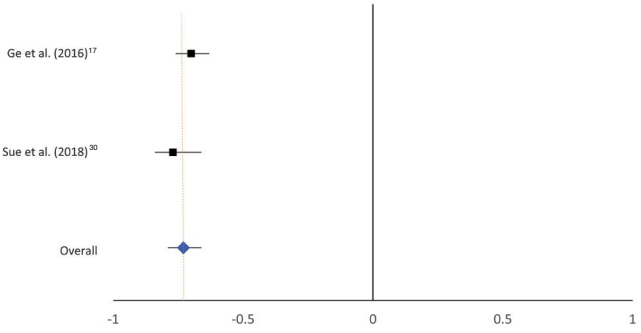

Fig. 14. Forest plot of the correlation between pulp volume and age in the maxillary first molars.

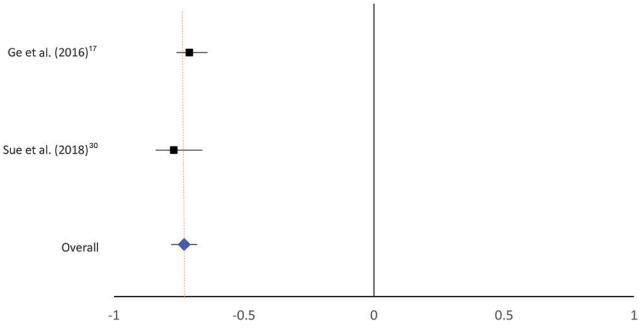

Fig. 15. Forest plot of the correlation between pulp volume and age in the maxillary second molars.

that the heterogeneity between studies was 20%, which was low. The Begg test indicated no significant probability of reporting bias ($P > 0.05$).

Discussion

Dental radiography is a noninvasive method for determining dental age. The ability to perform this technique in living subjects, along with other benefits such as low cost, accessibility, and repeatability, has led many researchers to investigate this method in more detail.

Due to the widespread application of CBCT in various fields of medicine and dentistry, as well as the applications of radiographic images in medical jurisprudence, several studies have been conducted to investigate its ability to be used for age estimation. CBCT is of interest to the medical community even though panoramic radiography is widely available and imposes a lower radiation dose, since CBCT imaging provides much greater quality and detail. Therefore, most studies today have focused on applying CBCT and its 3D reconstructions for DAE.

Due to the importance and practical relevance of dental age in medical jurisprudence studies, numerous studies have been conducted on this issue, and the relevant literature must be carefully analyzed in order to make correct decisions. These studies have used various software programs to calculate metric and volumetric indices.

The results of existing studies have generally indicated a strong inverse relationship between pulp volume and age. The pulp chamber volume decreases with age. An analysis of the subgroups yielded different results depending on sex and the type of tooth (single- or multi-rooted) and its position in the mandibles. The strongest and weakest relationships were observed in the mandibular first molars and mandibular third molars, respectively. This can be attributed to the availability of fewer studies on multi-rooted teeth (most studies have been conducted on single-rooted and anterior teeth) and the fact that the first molar is the first tooth to grow and plays a key role in occlusion. The subgroup analysis by sex indicated a stronger relationship among the female population, but without a statistically significant difference from the male population.

The evidence presented in other articles confirming the findings of the present study and the applications thereof will be reviewed. It is recommended to perform more studies on teeth, about which few articles have been written. Furthermore, due to the lack of studies on multi-rooted teeth, it is recommended to conduct more studies on multi-rooted teeth in subjects with a specific and limited age range.

A limitation of this study is that it only included English-language articles only. Therefore, it is suggested that non-English articles be included in future studies, since the findings of those articles could also be applicable in medical jurisprudence and other fields.

CBCT has a significant ability to assist in DAE. The data analysis showed a strong inverse relationship between pulp chamber volume and age. The mandibular first and third molars showed the strongest and weakest relationships, respectively, and the female population showed a stronger relationship than the male population.

Conflicts of Interest: None

Acknowledgments

This study was partially adapted from an MD thesis (number: 140007205832) in maxillofacial radiology, which was supported by the Vice-Chancellor of Research and Technology, Hamadan University of Medical Sciences, Hamadan, Iran.

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