CT and MR imaging used in age estimation: a systematic review

Mai Britt Bjørk[1]
Sigrid I. Kvaal[1]

[1]Institute of Clinical Dentistry, Faculty of Dentistry, University of Oslo

Corresponding author:
skvaal@odonto.uio.no

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ABSTRACT

Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) may be useful tools in assessment of age of an individual. This article presents a review of published studies using CT or MRI in dental age estimation. They were published between July 2004 and September 2017 investigating different types of teeth, methods and formulae for age estimation. Twenty-seven articles were included. The different studies show good results, and it seems that a combination of different types of teeth, methods (depending on the degree of root formation) and cooperation between different disciplines in the same study gives a higher accuracy.

INTRODUCTION

An English dentist named Edwin Saunders is said to be the first to apply tooth development in age estimation when he published a pamphlet to the English Parliament in 1837.[1] Since then several articles have been written regarding dental age estimation and many methods have been described. In 1896, one year after Conrad Röntgen discovered X-rays, radiology was first used in forensic science. Since 1955 radiology has been an important tool in age estimation.[2] Teeth are appropriate to use in age assessment because they are very resistant to time, mechanical, chemical and physical influences. They are also very little influenced by environment, nutrition and living conditions.[3]

Age estimation is important in forensic medicine both for unidentified human remains and living individuals in single cases as well as in mass disasters. It is also one of a number of methods to determine if a person is an adult or a child in asylum applications, in youth sports, immigration and adoption, and in criminal as well as civil procedures. It is also important in orthodontic and paediatric dentistry and in anthropology. In living individuals, the recommendation is that, the age assessment is made by evaluation of growth and development on radiographs of the teeth, a physical examination and a radiograph of the hand and/or radiographs or CT of the clavicles.[4] The highest reliability for dental age estimation occurs when several teeth are in development (until the age of 12-14 years), and the most common methods in use have been tested by several researchers both theoretically and in practice.[5] As a person grows the age estimations are relatively more imprecise because of the high variability of physiological age indicators.[5] The third molars are the only teeth still developing after the age of 16 years and up to late teens early twenties. These teeth are therefore used in age estimation of adolescents and young adults, but they are also the most variable tooth regarding time of formation and development.

Many methods have been applied to assess a person's age. The most common methods have been presented by Demirjian et al. in 1973, Moorrees, Fanning and Hunt (MFH) in 1963, London Atlas of Human Tooth Development and Eruption (QMUL) in 2010, Mincer et al in 1993, Olze et al. in 2005 and different formulae to determine the ratio between pulp and tooth volume like Kvaal et al. in 1995 and Cameriere in 2004.[6-11] The methods grade or measure dental development into mineralization and eruption stages, secondary dentine deposition and the degree of root formation.

In 2009-2010 the radiographic visibility of the periodontal ligament and of the root pulp of the fully mineralised mandibular third molars was assessed by Olze et al. [12,13]

Periapical radiographs and OPG are conventional radiographic methods that show two-dimensional images. Since the late 1990s several articles have been written about three-dimensional imaging: Computed Tomography (CT) came in 1972, Micro Computed Tomography (Micro-CT) in early 1980s, Cone-Bean Computed Tomography (CBCT) in 1996 and x-ray free imaging like Magnetic Resonance (MR) came in 1985.

CT scans are non-invasive, practical, cause no magnification errors due to geometric distortion, and present three-dimensional (3D) images of the third molar whether it is angulated or superimposed on adjacent structures.[14] Micro-CT is even more accurate, but is best in small areas and on extracted teeth.[15] Vaandevoort et al. (2004) were the first who investigated the potential of using Micro-CT in age estimation.[16] CBCT gives more detailed information, less artefacts, is cheaper and has a lower radiation dose than CT, but is not used as a routine in forensic medicine.[17] Multi-detector computed tomography (MDCT) is often used in forensic medicine since it has become more common to perform a post-mortem CT before autopsy.

The disadvantages with CT scans is the high radiation dose, high costs and artefacts caused by metal materials in for example fillings and implants (especially in the molar region). In countries were radiation is not recommended or allowed, some research with x-ray free imaging (MRI) has been tested for age estimations based on molar development. Both CT and MR imaging are dependent on good scanning protocols that provide the desired spatial resolution to distinguish what we are looking for within a clinically acceptable acquisition of time.[18]

The aim of this article is to give a review of the articles that have been written about estimating age from CT and MR imaging. The articles written on this topic have different limitations, selection of teeth and methods employed. This present article will try to sample the literature and find the gaps, problems and advantages which can lead us to further research.

MATERIALS AND METHODS:

Criteria for the selection were restricted to original articles of three-dimensional (3D) imaging in human dentition published in English after July 2004 and up to September 2017. Two-dimensional (2D) imaging was not included. The chosen articles were analysed and the characteristics of each article were systemized to give a short overview of the main points. A search was made in the following data-bases: Pubmed, Springer Link, Directory of open journals (DOAJ), Science Direct Journals (Elsevier), Oria, Annex Publishers, DentoMaxilloFacial Radiology (DMFR), RSNA, Wikipedia, Wiley Online Library, Digital Medicine, Journal of Oral Medicine and Pain (JOMP), Cochrane Library, Ovid and Google. Search words were: CT, MRI, age estimation, forensic dentistry.

RESULTS

The initial search resulted in 155 articles and after excluding 2D imaging there were 27 articles which included dental age estimation and 3D imaging for the review. These are presented in Table 1. The table shows that there are several methods used in age estimation with 3D imaging (Demirjian et al., MFH, multi-factorial with bones and teeth, Mincer et al., Olze et al., and calculations of the pulp/tooth volume). 23 articles with CT imaging include both single- and multi-rooted teeth while in MR imaging (4 articles) studies only multi-rooted teeth (molars) are included.[19] Studies with a large sample and an even age distribution for both males and females had the highest correlation coefficient. The coefficient varied in single- or multi-rooted teeth and in which calendar year the research was carried out.

DISCUSSION

To see if CT and MR imaging are useful tools in age estimation it is best to focus on the research with a large number of teeth and an even distribution of age in the test population, the highest correlation coefficient and comparison with conventional radiographs, so that we can see if the method can be an alternative to two-dimensional imaging.

In all articles the selection criteria were also good health, normal growth and dental conditions, and in the case of third molars no head injuries that affected the visualization of the tooth.[14] Teeth with metal restorations were excluded on CT because of the artefacts.[15]

The year the research was carried out is important because the imaging quality is better when modern machines are used and the scanning protocols have improved with experience. The various CBCT systems available differ with certain technical characteristics like the spatial resolution, the field of exploration and the contrast.[20] With large sample sizes and the newest CBCT operating modes and optimized software the research will be even more reliable.[20] The latest multi-detector scanners are able to provide thinner slice thickness which is optimal for assessing dental development.[5] All this can influence the accuracy.

As several studies have shown that there are differences in development between girls and boys, both genders ought to be represented.[21-24] Aboshi et al. used mandibular premolars as they are less prone to damage when compared to canines and incisors and they have simpler and more stable root morphology when compared to molar teeth.[25] There might be differences between upper and lower jaw as well as regional variations, but there is no difference between right and left side of the jaw.[14,23,24]

The stage of tooth development determines the method of age estimation. Pulp cavity/tooth volume is used when the roots are completed, while methods with different eruption and mineralisation stages and charts are used in age estimation in children and adolescents when the teeth are still developing.

The Demirjian et al. stages were used by Bassed et al. for the mandibular third molar when comparing CT with OPG.[5,26] This study reported some disagreements so Cantekin et al. decided to use CBCT images. Statistical analysis showed strong correlation between age and third molar development for both genders.[14] Cameriere et al. compared measurement of open apices of third molars and Demirjan stages to test chronological age over 18 years old in living subjects with 2D imaging.[27] This could also be used with 3D imaging.

The MFH stages of tooth development has also been tested on CT images with two people estimating, one experienced and one inexperienced.[28] Ages were underestimated by 10% using MFH method. Still compared to chronological ages, the accuracy rates of estimated ages based on CT was high (0,8-0,9 where the ratio of 1,0 indicated that the estimate was identical to the chronological age of each case).

With the individual variations of the root development of a third molar[5] cooperation between disciplines (forensic odontology, medical imaging, human growth and development and anatomy) might be required to maximise the accuracy of age estimates. In 2011 Bassed et al. carried out research using CT imaging and a multi-factorial method using the third molar tooth, the medial clavicular epiphysis and the spheno-occipital synchrondrosis.[26] Using only the third molar and the clavicle gave a good result. It seems like the uncertainty is higher the older the individual is, and this method may only be used when selected dental and skeletal sites are not fully developed.

The dimensions of the dental pulp show negative correlation with age. Kvaal et al. in 1995[29] described a non-destructive method for age estimation by linear measurements on radiographs. Two-dimensional images accumulate only horizontal and parallel aspects of the tooth, not the complete three-dimensional morphological changes of the pulp. Because of the fast-developing technology of CT machines, only research written after 2009 and research with large samples are relevant today. Ge et al. in 2015 used first molars and concluded that the pulp chamber is a useful index for age estimation, but gender and tooth position plays an important role.[30] Therefore, it is recommended to use gender and tooth specific equations.

Agematsu et al. and Sakuma et al. found a significant difference between gender and tooth position. A higher correlation between reduction in pulp volume and aging was observed in females than in males and a higher correlation between aging and decrease in pulp size was observed in the mandibular central incisors than in the mandibular second premolars.[15,31] There was also a difference between Micro-CT and MDCT. The age-related formation of the secondary dentine is directly related to the decrease of the pulp cavity volume while the volume of an entire tooth was mainly affected by the attrition of the enamel. Thus, a pulp cavity/tooth volume ratio may not reflect the real change from secondary dentine deposition, they found that the pulp chamber volume was more accurate than the volume calculation of the whole tooth because of high image contrast between dentine and pulp chamber. Micro-CT is more accurate, but the average difference in this study was less than in earlier studies. The explanation may be modern machines. It will always be more difficult to define the junction between enamel, dentine and pulp in CT images than in OPG, but the contrast is getting better with new technology. From table 1 it is evident that studies with small samples give low correlation coefficient.[16,32-34] The correlation coefficient is also higher when using Micro-CT which give more accurate measurements because of more spatial resolution than CBCT and CT.[22,25,31] Though the latest research after 2013 shows that it is possible to achieve high correlation coefficient with large samples and modern machines. The research should simplify dental volume measurements through geometric approximation of the different parts of the tooth. It is important to remember that it easily can be inaccurate measurements because of the difficulty to find exactly the junction between tooth structures like the pulp-dentine junction. In addition, some teeth can have irregular volumes. The time may differ between methods and may vary from less than 15 minutes up to 3 hours, but shorter exposure times may require higher doses and incur larger costs.[25,32,34]

Ge et al. (2015) investigated pulp chamber volume of first molars in relation to age on CBCT images in a large sample with focus on multi-rooted teeth.[30] Because of the complex root system of first molars and to simplify the segmentation procedure, it was decided to calculate the volume of the coronal pulp chamber with age. The difference in volume between genders and the difference between the volumes of maxillary molars and mandibular molars was significant.

Another study by Ge et al. had only an average difference of 4% between the pulp volumes in multi-rooted molars and 6% in single-rooted premolars obtained from Micro-CT and CBCT.[35] The study tried to find out which type of tooth in the same dentition had the best relationship between age and pulp cavity volume in 13 types of teeth. The teeth were divided into single- and multi-rooted teeth excluding third molars. The total volume of tooth pulp cavity was calculated while for multi-rooted molars the pulp chamber floor was set as the “cut plane” because of the complex root system. The maxillary second molar gave the highest correlation coefficient with age (both in male, female and pooled gender samples). The maxillary canines showed the lowest correlation coefficient between volume and age. The explanation may be the difference in function of the teeth and location in the arch. The canines are located at the turning point of the dental arch and after reconstruction, the 3D images at a turning point will be less clear and accurate than those obtained at a planar field where the molars are located. The pulp chamber of the molars is also bigger so it is easier to see the junction between pulp and dentine.

Tardivo, et al. presented the highest correlation coefficient when using canines.[33] He chose canines because of their high level of survival, they undergo less wear, they have the largest pulp volume compared to other single-rooted teeth and the mandibular canines present the most important sexual dimorphism. This research also had a reasonably large sample with an even age distribution for both males and females. Maybe the results would have been even better if he had also used the maxillary second molar as GE et al. did, or maybe Tardivo et al. had a better protocol that minimized the importance of the location at the dental arch.[33,35]

Penaloza et al. used the Kvaal method on volumetric data from CBCT and concluded that it was less accurate because in some cases the border between the pulp chamber and the dentine, or tooth and bone was more blurred than in dental radiographs. There was also a difference in resolution between the different machines and settings. It was also more time consuming than using 2D images because of the need to properly align the teeth in the sagittal and coronal plane.[36] Volume calculations depend also on a good software.[37,38]

In most countries it is not ethically acceptable to use radiation without a diagnostic indication in living individuals. Therefore, research with MR imaging as a tool in age estimation has been performed. The research is quite new, presented in 2015 and has used the Demirjian’s stages of tooth development and Olze’s stages on eruption on molars. Baumann et al. did a study with two separate and independent dentists who evaluated the different stages of mineralization and eruption of the molars in all four quadrants - one using OPG and the other MRI.[24] The different stages could be identified equally well both for OPG and MRI. It was easier to evaluate the mineralization stages on MRI than OPG because the roots on OPG are often superimposed (OPG is a projection method). It was the opposite with the evaluation of the eruption stages because the dental crown is prone to metallic artefacts in MRI (the roots are not influenced by artefacts). The results showed that MRI has a tendency to give lower stages compared to OPG. The mineralization stages can also be affected by the imaging procedures. In the dental follicle mineralised dental tissue is surrounded by watery content creating sufficient contrast, so early stages of tooth development are clearly displayed on MRI. Later stages are more challenging, as the most significant characteristics are the remnant of the dental follicle and closing of the apex.[39] In these stages the lack of contrast between dental tissue and bone can make the measurement difficult and inaccurate. Therefore, in MRI imaging it is very important to use a protocol which optimises the contrast. Baumann et al. also observed method-dependent differences with regard to the mineralization stages in some of the examined molars.[24] MRI is radiation free, but at present takes more time and is much more expensive than OPG. Another factor which must be considered is gender differences in tooth development.[21]

It has been shown that the image quality in OPG was lower in older age groups and higher in women than in men.[40] This is explained by forensic investigations as age-related changes of the dental pulp and sex differences of the skull geometry and this must also be considered in three-dimensional imaging.

De Tobel, et al.'s study showed that images taken in the sagittal plane gave 100% assessable mandibular third molars, compared to 58.8% in the axial plan.[18] The same study tried to develop the best protocol (to visualise all third molars) suitable for forensic age estimation, but a control study is needed to see if this protocol can be used.[18] The research concluded that if a method for age estimation with MRI is used, a sequence with an almost isotropic voxel size is necessary. The difference between the in-plane resolution and the slice thickness should be limited. Stern et al. has developed a method like this for left hand MRI.[41] It is also important to study further whether MRI in all planes is necessary, or if it is sufficient with only one plane. Reference samples should be scanned with suitable protocols, all stages of the third molars and include individuals from 8-24 years.[42] De Tobel et al. found the appearance of third molars on MRI different from the dental radiographs and created an appropriate staging technique.[43] The study confirmed that the mandibular molars were in the same or more advanced stages than the maxillary ones, but no difference was observed between left or right side in the same jaw. In up to 2.2% of the control measurements a two-stage difference occurred between the observers.

There are no recommendations on how to present research in this field, and the various statistical analyses have different limitations. Bias can occur in the planning, data collection, analysis and publication phases of research. The size of the test sample (individuals of known age) in a study is important to get reliable results. It is also important to include an equal number in each age group and an age range which covers the variation in the test population to avoid age mimicry. For example, an age group of 20-80 years needs more than hundred because this will only give 1.67 each year. Both genders must be equally represented and intra- and inter-observer accuracy and repeatability of the measurements must be tested. It is important that the technical error of measurements is as low as possible and the coefficient of reliability is as high as possible. Gelbrich et al. said that only reference data with uniform age distribution or adequate correction for potential bias should be cited for forensic age estimation.[40] Reference data with low bias and small values of mean absolute difference are recommended to estimate age and point estimates and age intervals should be accompanied by a measure of variation.[44]. In the assessed studies some of the criteria mentioned above is not fulfilled: too small samples, the sexes are pooled and the sample do not have an even age distribution. On the other hand, some of the studies are results of cooperation between different researchers.

The most common statistical method in age estimation is regression analysis.[45] The Demirjian method frequently overestimates young individuals and underestimates elderly individuals when using this analysis.[6,45] The most appropriate

statistical method is maybe a model that allows for multiple related age predictors to be integrated for age estimation e.g. the Bayesian model.[43]
It seems that when different age-related changes are used together it gives higher confidence than when one is used on its own.[26] This needs more research and can be the ultimate method for age estimation when collaborating conventional radiographs with CT or MRI of the hand/wrist and other skeletal changes. Maret et al. had an hypothesis that quantitative measurements of the alveolar bone and surrounding cortical bone could be combined with other variables like the volume of each component of the teeth to estimate the age of a living subject.[20] Swasty et al. evaluated the cortical thickness, height and the width with CBCT and determined the relationships between these parameters and age.[46] The variations of these mandibular variables indicated changes in overall shape that were dependent on age and probably the forces generated during function.[20] Other factors that could influence the cortical thickness and anatomy were face type and gender.

Table 1. Characteristics of the chosen articles

Author	Year	Country	Total amount	Age	Sex	Teeth	Method	Imaging	correlation results
Vandevoort, Cleynenbreugel, Bielen, Lambrechts, Weves, Peirs and Willems[16]	2004	Belgium	43	24-66	N/A	Single-rooted teeth	Pulp/tooth volume	Micro-CT SkyScan byba	r=0,31
Yang, Jacobs and Willems[32]	2006	Belgium	19	23-70	11 f 8 m	Incisors, canines and premolars	Pulp/tooth volume ratio	Cone-beam CT- 3D Accuitomo	r=0,29
Someda, Saka, Matsunaga, Nakahara, Hirata and Hashimoto[22]	2009	Japan	155	12-79	79 f 76 m	Mandibular central incisors	Volumes of enamel, dentine and pulp cavity	Micro-CT-HMX225 ACTIS4	r=0,67 m r=0,76 f volume ratio pulp cavity/ tooth volume excluding enamel
Graham, O`Donnel, Craig, Walker, Hill, Cirillo, Clark, Gledhill and Schneider-Kolsky[28]	2009	Australia	96	<15	N/A	Incisors Deciduous Permanent	MFH (Moorrees, Fanning and Hunt) Experience-based estimation	CT-Toshiba	r=0,9
Bassed and Hill[43]	2010	Australia	2	0,5-3,5 year	N/A	N/A	Demirjian	CT-Toshiba Aquilion 16	Useful tool in identification
Aboshi, Takahashi and Komuro[25]	2010	Japan	50	20-78	23 f 27 m	Mandibular first and second premolars	Pulp/tooth volume	Micro CT-SMX-130CT-SV	r=0,625 mandibular first r=0,698 mandibular second

Agematsu, Someda, Hashimoto, Matsunaga, Abe, Kim, Koyama, Naito, Ishida and Ide[31]	2010	Japan	N/A	20-79	75 f 73 m 54 f 56 m	Mandibular central incisor Mandibular second premolar	Pulp/tooth volume	Micro-CT HMX225 ACTIS4	r=0,75 r=0,67 r=0,58 r=0,56
Tardivo, Sastre, Ruquet, Thollon, Adalian, Leonetti and Foti[33]	2011	France	58	14-74	32 f 26 m	Canines	Pulp/ tooth volume	CT	r=0,32 f r=0,47 m
Bassed, Briggs and Drummer[5]	2011	Australia	667	15-25	216 f 451 m	Mandibular third molar	Demirjian	CT-Toshiba Aquilion 16	100 % females and 96 % males with completed roots were over 18 years old
Bassed, Briggs and Drummer[26]	2011	Australia	605	15-25	184 f 421 m	Mandibular third molar, clavicle and an intact spheno-occipital synchondrosis	Demirjian Schulz Powell and Brodie	CT-Toshiba Aquilion 16	These three methods used together gives 95 % confidence than when each marker is used alone
Star, Thevissen, Jacobs, Fieuws, Solheim and Willems[34]	2011	Belgium	64 32 15	10-65	N/A	Central Incisor Lateral Incisor Canine First premolar Second premolar	Pulp/tooth volume	CBCT Scanora 3 D	r=0,41 r=0,07 r=0,23
Jagannathan, Neelakantan, Thiruvengadam, Ramani, Premkumar, Natesan, Herald and Luder[48]	2011	India	140	10-70	N/A	Mandibular canines	Pulp/tooth volume	CBCT 3D Accuimoto	r=0,397
Sakuma, Saitoh, Suzuki, Makino, Inokuchi, Hayakawa, Yajima and Iwase[15]	2012	Japan	136	14-79	31 f 105 m	Mandibular first premolars	Pulp cavity/ tooth volume	CT-NewTom 3G	r=0,76 and 95% confidence
Cantekin, Sekerci and Buyuk[14]	2013	Turkey	649	9-25	319 f 330 m	Mandibular third molar	Demirjian	Cone-beam CT-NewTom 3G	r=0,78 f r=0,80 m

Tardivo, Sastre, Catherine, Leonetti, Adalian and Foti[33]	2014	France	840	15-85	N/A	Canines	Pulp/tooth volume	CT-Siemens sensation	r=0,915-0,964
Porto, Neto, Pontual and Catunda[49]	2015	Brazil	118	22-70	60 f 58 m	Maxillary central incisors	Pulp cavity / tooth volume ratio	Cone-beam CT i-Cat Next Generation	r=0,21 r=0,15 m r=0,297 f
Ge, Ma, Li, Zhang and Ma[30]	2015	China	373 maxillary 372 mandibular	12-69	N/A	First molar	Pulp/tooth volume	Cone-beam CT NewTom VG Micro-CT	Significant differences in sex and tooth position r=0,66 maxillary r=0,604 mandibular More accuracy than CBCT
Pinchi, Pradella, Buti, Baldinotti, Focardi and Norelli[50]	2015	Italy	148	10-80	91 f 57 m	Maxillary left central incisors	Pulp/tooth volume	CBCT Scanora 3D	The age cohorts between 30 and 59 years showed the highest accuracy r=0,58
De Angelis, Gaudio, Guercini, Cipriani, Gibelli, Caputi and Cattaneo[51]	2015	Italy	91	17-80	49 f 42 m	Maxillary right third molar	Pulp/tooth volume	CBCT-i-cat Next Generation	r=0,485 r=0,263 Total r=0,389
Baumann, Widek, Merkens, Boldt, Petrivic, Urshler, Kirnbauer, Jakse and Scheurer[24]	2015	Austria	27	13,6-23,1	19 f 8 m	Molars (262, mineralization, 274 eruption)	Demirjian and Mincer (mineralization) Olze (eruption)	MR MagnetomTrio,a Tim System,Siemens AG	Good correlation between MRI and OPG MRI tended to give slightly lower stages
Guo, Olze, Ottow, Scmidt, Schulz, Heindel, Pfeiffer, Vieth and Scmeling[21]	2015	Germany	517	12-24	248 f 269 m	Mandibular third molars	Demirjian	MR Philips 3,0 Achieva	MRI is an X-ray free alternative to OPG in assessing mineralization
Ge, Yang, Li, Zhang and Ma[35]	2016	China	240	16-63	115 f 125 m	13 types of teeth	Pulp/tooth volume	CBCT-New Tom VG	Maxillary second molar has the best result r=0,64

Penaloza, Karkhanis, Kvaal, Nurul, Kanagasinga, Franklin, Vasudavan, Kruger and Tennant[36]	2016	Australia	101	15-75	55f 46m	Maxillary central and lateral incisors and The second premolar Mandibular lateral incisor, canine and first premolar	Kvaal	CBCT both Kodac and i-Cat.	The accuracy was outside an acceptable range and more time consuming than dental radiographs.
De Tobel, Hillewig and Verstraete[39]	2016	Belgium	52	14-26	N/A	Third molars	Demirjian and Köhler	MR Magnetom, a Tim system, Siemens AG	3T MRI has advantages compared to OPG, but further research is necessary.
Màrquez-Ruiz, Trevino-Tijerina, Gonzàlez-Herrera, Sànches, Gonzàles-Ramirre and Valenzuela[37]	2017	Spain	135	14-23	62f 73m	Maxillary and mandibular third molar	Demirjian Pulp/tooth volume	Multi-slice helical high resolutionLigt-Speed VCT CT system	Virtual CT imaging is an alternative to OPG for the assessment of third molar mineralization.
Penaloza, Karkhanis, Kvaal, Vasudavan, Castelblanco, Kruger and Tennant[38]	2017	Australia	21	15-63	12f 9m	Maxillary canines	Pulp/tooth volume	CBCT 9000 3D Extraoral Imaging System	Not showing better results than methods based on dental radiographs.
De Tobel, Phlypo, Fieuws, Politis, Verstraete and Thevissen[43]	2017	Belgium	309	14-26	146 f 163 m	Third molars	To develop an MRI specific staging technique for the development of third molars	Magnetom Trio Tim, Siemens	The new staging technique showed comparable reproducibility and performance.

Abbreviations:

Total amount: number of participants	f: female	m: male
N/A: not applicable	Age= years	OPG: Orthopantomography
MR: Magnetic Resonance	MRI: Magnetic Resonance Imaging	CT: Computer Tomography
CBCT: Cone-beam CT		

CONCLUSION

Both CT and MR imaging may be useful tools in age estimation, but more research is needed before these tools can be used for this purpose. Since CBCT is more commonly used in dental clinics, more image samples for retrospective studies may be available in the future. Further and extensive research may also lead to new methods in which mandibular third molars are used to determine if a person is younger or older than eighteen years of age. It would also be interesting to do more research in cooperation with x-ray and/or CT of the hand/wrist region and clavicles to get as accurate a result as possible. The quality of the machines and scanning protocols are improving and will give better standards of the images. This will give us possibilities for research with larger numbers of test subjects and therefore even more reliable results and more specific conclusions.

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