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# Tooth coronal index and a new staging system for dental age estimation in southern Turkish population

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**ABSTRACT**

Dental age indicators should be evaluated in different populations. The aim of the study was to evaluate the accuracy of the estimated age results of tooth coronal index (TCI) and to develop a new staging system using panoramic radiography for the southern Turkish population. The study group consisted of panoramic radiographs of 1000 individuals aged 11–77 years. The study group was divided into four subgroups according to age of patients: Group 1 (11–18 years of age), Group 2 (18–29 years), Group 3 (30–50 years), Group 4 (51–77 years). The mandibular first molar was measured. TCI and a new staging system were assessed in the southern Turkish population by two observers. The novel model includes six new parameters. Multiple regression models, intraclass correlation coefficient and Durbin-Watson analysis were used. The estimation error of TCI and the novel model were 14.25 and 11.04, respectively. The parameters of the novel model were more powerful than TCI's. There was no significant difference in sex. For both methods, the estimated age in Group 3 (between 30–50 years) provides the highest accuracy in all age groups. The results showed that the novel age estimation model is more reliable in the southern Turkish population.

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**KEYWORDS**
Forensic odontology; dental age estimation; tooth coronal index; panoramic radiography

## Introduction

Age estimation is an important aspect of forensic and anthropological practice [1]. Due to economic and political reasons, the migrant population has increased among countries in recent years. The International Organization for Migration reported that 3.5% of the world's population (272 million) migrated in 2019 [2]. As the processes of global migration deepen, the number of foreigners who do not have documentary evidence of birth date is increasing. Hence, the age determination of living individuals for medico-legal, civil, and social purposes has become a crucial aspect of forensic science [3].

Dental and skeletal age indicators are evaluated to determine chronological age. Age estimation methods should be based on tissues and organs that are least affected by environmental and hormonal factors, and metabolic diseases. However, tooth and skeletal systems have different developmental processes in ageing. While the embryonic origin of the tooth structure is ectomesenchyme, the skeletal tissue is mesoderm [4]. Therefore, tooth

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development and maturation stages are biological processes independent of skeletal development that are affected by many chemical, mechanical, and hormonal stimulations [5].

Many methods based on histological, morphological, and biochemical determinants can be used for dental age estimation. However, some methods involving cross-sectioning of the tooth and chemical analysis are destructive because they require tooth extraction and their use is limited to deceased individuals [6]. Furthermore, destructive methods such as amino acid racemization and dental nuclear tests are time-consuming and expensive [7]. To determine the chronologic age, the Forensic Anthropology Society of Europe and Study Group on Forensic Age Diagnostics recommend the examination of dental radiographic images. Radiographic examination is non-invasive, easy-to-access, and can be used in both deceased and living individual s[8].

Dental age determination is very useful in the forensic field to identify cases thanks to different age-related dental development stages and secondary dentin accumulation that continues in adulthood. In children, dental age estimation is generally based on the degree of mineralization of dental hard tissue observed in panoramic radiographs. However, morphological changes observed after the root formation and mineralization of the dentition are used for age determination in adults [9]. The formation of secondary dentin is one of these physiological processes in ageing teeth and can be considered as a dental age indicator [10]. Kvaal et al. [11] reported a method that secondary dentin accumulation observed on radiography was used as an age indicator. Secondary dentin deposition results in changes in pulp chamber volumes. Pulp width in the mesiodistal aspect and pulp height decreases with ageing [12]. Therefore, pulp dimension measurements can be used as a dental age indicator. Tooth coronal index (TCI) is a method that uses secondary dentin accumulation and pulp size as an age indicator [5]. In order to follow the age-related changes in teeth more clearly, the inclusion of multiple parameters and the use of non-misleading reference points increase the reliability of age estimation methods in adults.

Even though dental age staging methods can be used in different populations, the accuracy of these methods varies. Therefore, the applicability of the methods in populations should be evaluated. In addition, population-specific age estimation systems can be developed for the determination of chronological age. A previous study concluded that maximum accuracy in age estimation is ensured with regional and population-specific formulae [13]. However, Turkey is a large transcontinental country that was home to numerous ancient civilizations. Different ethnic populations, socio-economic differences, changes in climate may cause biological differences in Turkish subpopulations [14]. Thus, the study aims to evaluate the accuracy of the estimated age results of the tooth coronal index and to develop a new staging system using panoramic radiography for the southern Turkish population.

## Materials and methods

### *Study sample*

This retrospective study was approved by the local ethics committee. The study group consisted of 1000 patients (aged 11–77 years, mean age 33.67) who referred to the private dental clinic from June 2019 to 2020 for various dental complaints that were included in

this study. All panoramic images were obtained from Orthophos (Sirona Dental Systems, Bensheim, Germany) using Sidexis software. Age, sex, and date of the panoramic image of patients were recorded. Mandibular first molars with complete root formation and good diagnostic quality were measured.

The TCI method and the novel age estimation method using six different parameters were applied. The study group was divided into four subgroups according to age of patients: Group 1 (between 11 and 18 years of age, mean age 14.22), Group 2 (between 19 and 29 years, mean age 23.49), Group 3 (between 30 and 50 years, mean age 38.17), Group 4 (between 51 and 77 years, mean age 58.08). All measurements were performed by the same radiologist (four years' experience) and the endodontist (four years' experience). Fifty samples were re-evaluated by two observers to assess inter-observer and intra-observer agreement. Each observer was blinded to the data of patients.

## Exclusion criteria

Two-hundred and fifty-one patients were excluded from the study sample (42 patients with missing mandibular first molar, 72 patients with endodontic treated teeth, 23 patients with poor image quality in the selected area, 98 patients with decayed or restored teeth, and the canals of the mandibular first molar cannot be observed in panoramic radiography for 16 patients).

## Radiographic examination

*TCI method*: Coronal height (CH) was measured from the cementoenamel junction to the tip of the cusp. Coronal pulp cavity height (CPCH) was measured from the cementoenamel junction to the tip of the pulp horn (Figure 1). Then TCI was calculated as follows: $TCI = CPCH \times 100/CH$[5].

*New staging system*: Six measurements were identified on the panoramic radiographs for estimated age (Figures 2–5):

(1) Pulp horn (A) was measured from the furcation line to the tip of the pulp horn.
(2) Crown height (B) was measured from the furcation line to the highest dentin point.
(3) Pulp width (C) was measured from the midline of the pulp chamber.
(4) Crown width (D) was measured from the midline of the crown without including enamel.
(5) Root dentin thickness (RDT) was measured at 4 mm below the furcation.
(6) Distal canal width (E) was measured at 4 mm below the furcation.

## Statistical analysis

Statistical analyses were performed by using SPSS software version 22.0 (SPSS Inc., Chicago, USA). A multiple linear regression model has been applied for parameters of TCI and a new staging system. Intraclass correlation coefficient (ICC) and Durbin-Watson analysis were used to evaluate the reliability of measurements between dental age and chronological age. For intra-observer and inter-observer agreement, 20% of all samples were re-evaluated using ICC.

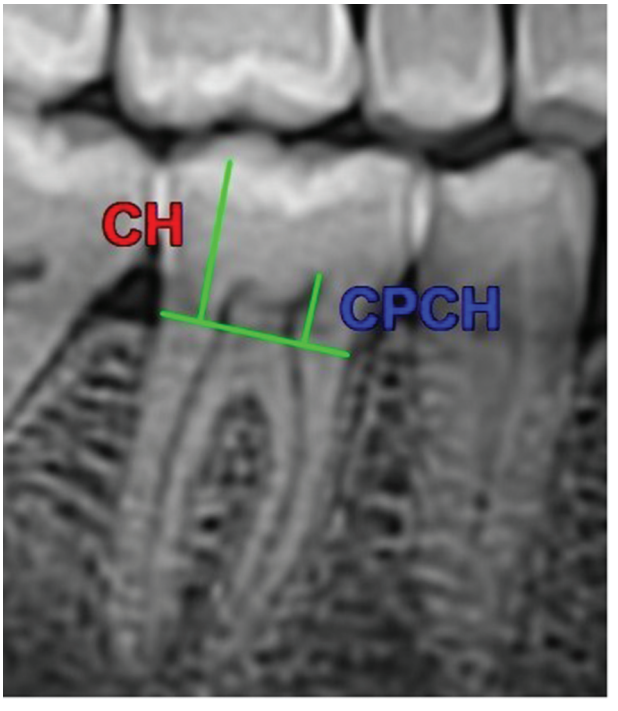


**Figure 1.** Left mandibular first molar measurements to calculate tooth coronal index on panoramic radiography. Coronal height (CH) was measured from the cementoenamel junction (red line) to the tip of the cusp. Coronal pulp cavity height (CPCH) was measured from the cementoenamel junction to the tip of the pulp horn.

## Results

The distribution of the study population according to sex and age groups is shown in Table 1. Data obtained from measurements were evaluated. There is a significant difference between age groups. Based on our results, a new staging system had more accurate findings than the TCI method (Figure 6). The estimation error of the two models according to the sex is shown in Figure 7. There was no significant difference in sex. For both methods, the estimated age in Group 3 (between 30 and 50 years) provides the highest accuracy in all age groups. Group 4 (between 51 and 77 years) had the lowest values compared with the other groups (Table 2).

The estimation errors of a new staging system and TCI were 11.04 and 14.25, respectively.

Regression analysis was used to assess the correlation between dental age and chronological age. Multiple regression models showed a poor correlation for the TCI model ($R^2$ = 0.204), but a powerful correlation for the novel model ($R^2$ = 0.652) to estimate real age. Regression formulae were calculated for the whole study population based on mandibular first molars.

The novel regression formula was formulated as follows:

$$\begin{aligned}\text{Dentalage} = {} & 48.775+(-0.262)^{*}\text{Sex(Male} = 1/\text{Female}{=}0)+(-5.139)^{*}\text{A} \\ & +(2.640)^{*}\text{B}+(-6.476)^{*}\text{C}+(2.239)^{*}\text{D}+(5.144)^{*}\text{RDT}+(-14.315)^{*}\text{E}\end{aligned}$$

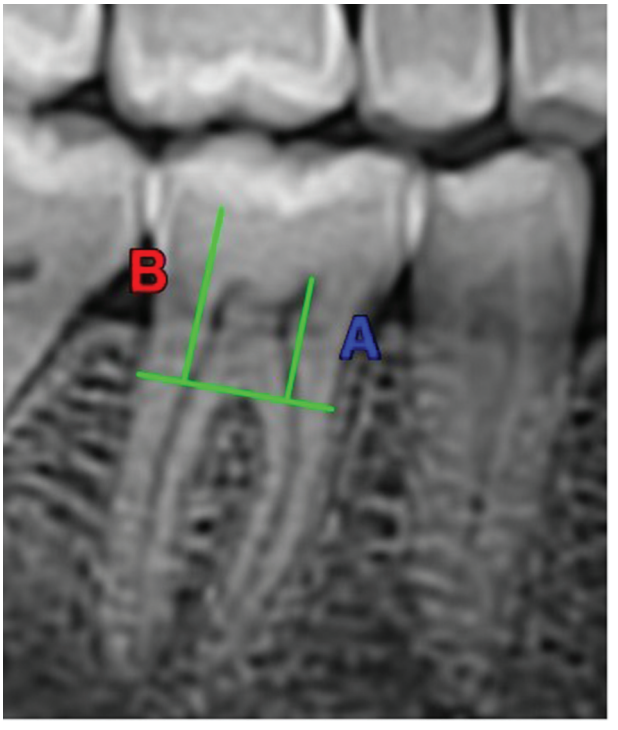


**Figure 2.** Left mandibular first molar measurements. Crown height was measured from the furcation line to the highest dentin point. The pulp horn was measured from the furcation line (red line) to the tip of the pulp horn.

If the sex of the individual is unknown, the novel regression formula was formulated as follows:

$$\begin{aligned}\text{Dentalage} = {} & 48,657 + A^{*}(-5,32) + B^{*}2,638 + C^{*}(-6,476) + D^{*}1,232 \\ & + \text{RDT}^{*}5,139 + E^{*}(-14,316).\end{aligned}$$

Regression formula for TCI method:

$$\begin{aligned}\text{Dentalage} = {} & 43.180 + (0.264)^{*}\text{Sex}(\text{Male} = 1/\text{Female} = 0) + (-0.493)^{*}\text{CH} \\ & + (-3.864)^{*}\text{CPCH}\end{aligned}$$

According to the ICC and Durbin-Watson analysis, the novel model has a more reliable estimate than the TCI model. Sex, CH and CPCH parameters do not contribute significantly to both models. These parameters may explain the poor results of the TCI model (Table 3).

Inter-observer and intra-observer agreement of parameters are shown in Table 4.

## Discussion

In forensic medicine, age staging methods are used for the identification of deceased individuals in criminal cases. Age is one of the important parameters in determining self-defence. In criminal law, crimes committed against adults who are unable to defend

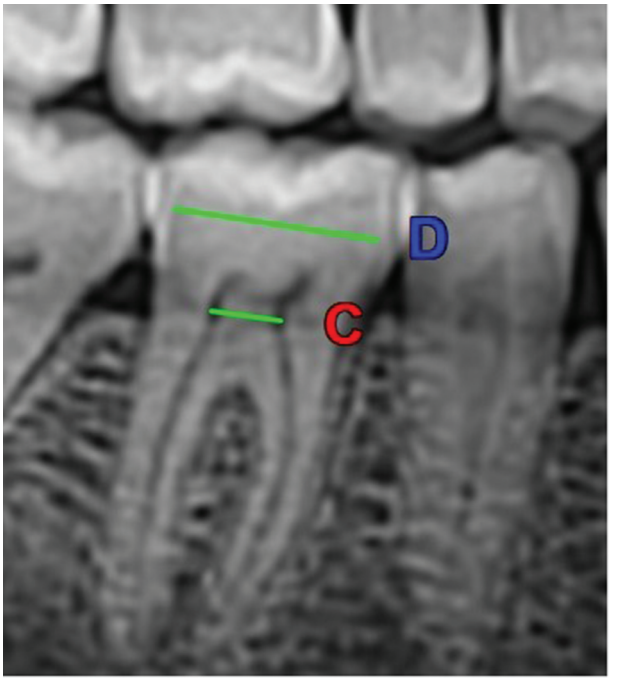


**Figure 3.** Left mandibular first molar measurements to calculate the novel model on panoramic radiography. Crown width was measured from the midline of the crown without including enamel. Pulp width was measured from the midline of the pulp chamber.

themselves affect legal consequences. Therefore, to determine the age of deceased adult individuals is crucial for criminal purposes [8]. In this study, a new staging system can be used for the age estimation of the adults.

In forensic science literature, there are numerous age estimation methods in adults. Skeletal age estimation methods in adult individuals can be challenged because of degenerative changes with age. To evaluate changes in the pubic symphysis, iliac auricular surface, sternal rib ends, and sternal end of the clavicle are the mostly used skeletal age estimation methods [15–17]. These methods were established based on age-related morphological and degenerative changes on the joint surface, such as osteophyte formation, ridges, and nodules. However, morphological changes can be related to extrinsic factors such as diet, physical activity, and medical condition [18]. Therefore, using multiple indicators and methods leads to more accurate estimate of age staging in adults. Besides of this, researchers indicated that dental age staging methods may be more useful than skeletal methods in young adults [19,20].

The current study evaluated both the applicability of TCI for the Turkish subpopulation. At first, Drusini et al. [21] investigated the effect of the TCI method on age determination. In this study, standard error was found to be ±5 years in 81.4% of all samples. Based on the findings of other studies assessed by the TCI method, estimation error for mandibular first molars was found to be ±6.3–9.85 years in the Western Australian population, ±5.52–7.85 years in the Malawian population, and 2.88–4.35 years in the Sulaimani population [22–24]. A similar study evaluated the reliability of the TCI method and there

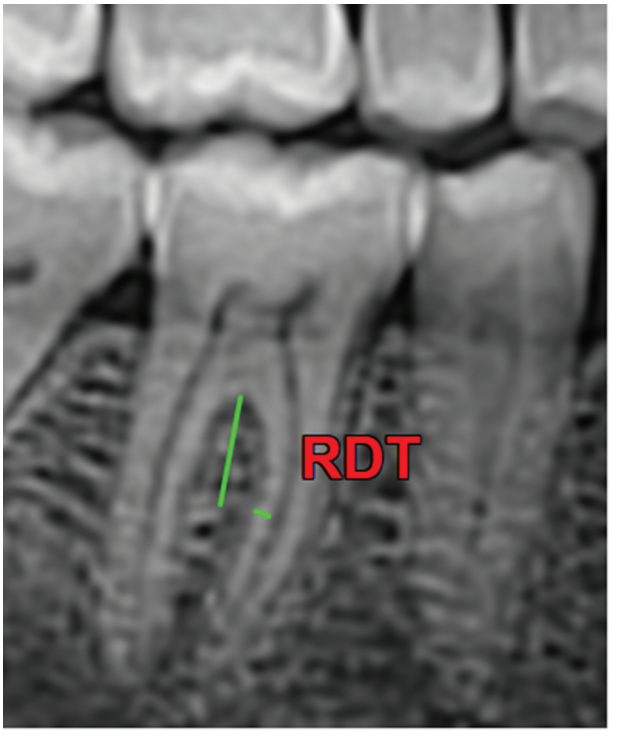


**Figure 4.** The distal root of the left mandibular first molar measurements to calculate a new staging system in panoramic radiography. Root dentin thickness was measured 4 mm below the furcation.

was a negative correlation between dental age and chronological age [5]. Another study found that accuracy levels of TCI were between 88.34% and 99% in the Indian population, and premolar teeth were more reliable than molar teeth [25]. Shresta et al. evaluated the applicability of TCI and Kvaal's method. Findings of this study revealed that TCI was a reliable marker in the 0–20 and 21–40 age ranges [26]. There are differences in the results of previous studies. Differences in results could be caused by small sample size, different populations, or different teeth types. Further studies with large sample sizes are needed to confirm the findings of previous studies.

A previous study performed by Akay et al. investigated the accuracy of TCI and Cameriere's method in the Turkish adult population [27]. According to the study, the TCI method had little correlation, whereas Cameriere's method had good correlation between estimated age and chronological age. Recently, another study evaluated the applicability of the TCI method to mandibular premolar teeth in the Turkish population [28]. The findings of this study indicated that the standard errors of estimates ranged from 10.01 to 10.96 years for the TCI method. Furthermore, there was no statistical significance with regard to sex. The results of previous research on the reliability of the TCI method in the Turkish population support our results.

In the current study, the reliability of the novel method among age groups was also examined. It has been reported that the applicability of the novel method is greatest between the ages of 30 and 50. The lowest relationship was found in the age ranges of 50–77 and 11–18. Secondary dentin deposition is the terminal and longest stage of tooth development and

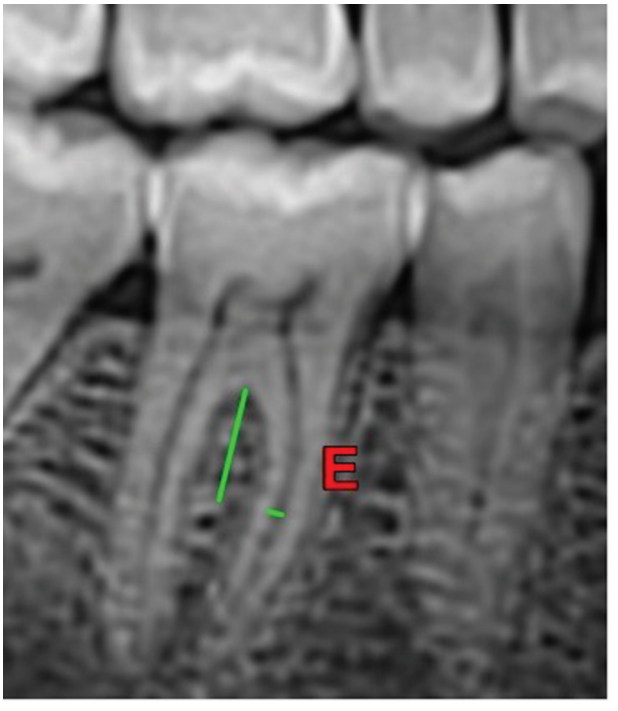


**Figure 5.** The distal root of left mandibular first molar measurements to calculate the novel method in panoramic radiography. Distal canal thickness was measured 4 mm below the furcation.

**Table 1.** Distribution of age subgroups and sex in the study sample.

| Age subgroups | Sex | Total |
|---|---|---|
| Group 1 | Female 69<br>Male 58 | 127 |
| Group 2 | Female 164<br>Male 158 | 322 |
| Group 3 | Female 184<br>Male 203 | 387 |
| Group 4 | Female 83<br>Male 81 | 164 |

continues throughout the remaining life of the tooth. It has a slower rate at the beginning of the process [29]. Therefore, it cannot be detected in panoramic radiography. Furthermore, secondary dentin formation cannot be observed since apex formation is not completed before the age of 14 [30]. These points can explain why the accuracy of the age estimation method based on secondary dentin accumulation is low in sub-adults. On the other hand, tertiary dentin formation due to different pathologies such as bruxism, chronic trauma, and attrition occurs in addition to secondary dentin accumulation [29]. The consequences of these pathological conditions become more evident at older ages. Tertiary dentin causes the parameter measurements to be blocked, resulting in inaccurate dental age estimation.

TCI uses the ratio of pulp height to crown height as an age indicator [5]. Secondary dentin distribution is not uniform in all pulp dimensions. Due to the accumulation of

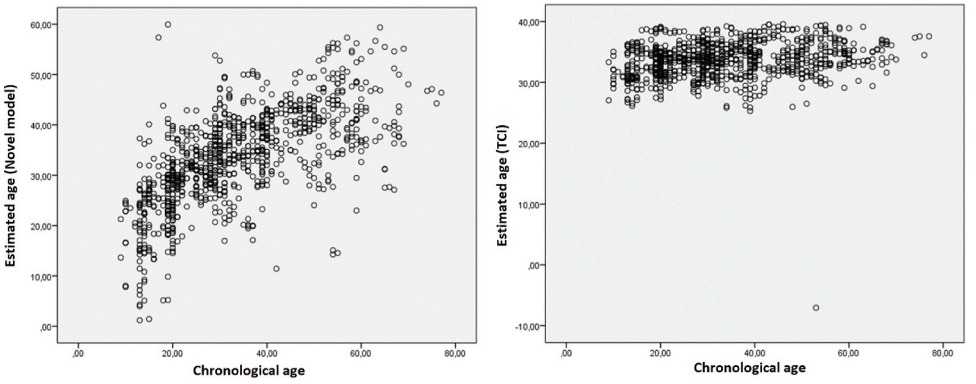


**Figure 6.** Comparison between estimated age and chronological age for the novel model (left) and TCI model (right).

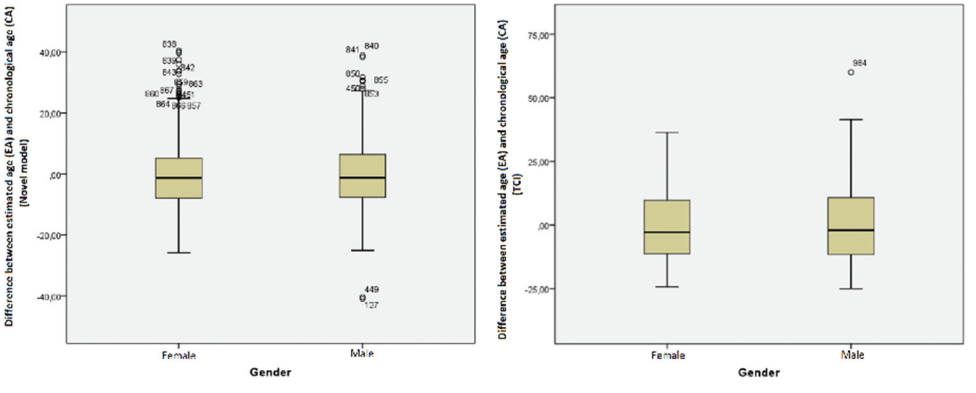


**Figure 7.** Difference between estimated age and chronological age according to sex for the novel model (left) and TCI model (right).

**Table 2.** Estimation error of two methods according to the age subgroups.

| | | *n* | Mean | Median | Minimum | Maximum | SD |
|---|---|---|---|---|---|---|---|
| Difference between the estimated age and chronological age (TCI) | Group 1 | 127 | −18.185 | −17.94 | −25.03 | −11.02 | 3.03 |
| | Group 2 | 322 | −9.879 | −10.18 | −19.80 | 0.22 | 4.24 |
| | Group 3 | 387 | 4.163 | 3.47 | −8.70 | 22.04 | 6.61 |
| | Group 4 | 164 | 23.665 | 22.80 | 12.26 | 60.06 | 6.61 |
| | Total | 1000 | 0.002 | −2.53 | −25.03 | 60.06 | 14.25 |
| Difference between the estimated age and chronological age (new age staging model) | Group 1 | 127 | −7.490 | −8.49 | −40.37 | 13.59 | 8.19 |
| | Group 2 | 322 | −6.524 | −6.82 | −40.95 | 13.80 | 6.01 |
| | Group 3 | 387 | 1.122 | 0.96 | −22.78 | 30.58 | 7.65 |
| | Group 4 | 164 | 15.955 | 15.79 | −2.46 | 40.46 | 9.92 |
| | Total | 1000 | −0.001 | −1.32 | −40.95 | 40.46 | 11.04 |

secondary dentin with aging, the decrease in pulp height becomes more than the decrease in its width [24]. However, using a single parameter reduces the reliability of the method due to local morphological variations. In the novel method, both the reduction in pulp height and pulp width due to secondary dentin deposition were used as parameters and were included in the regression formula. Furthermore, the

**Table 3.** Regression models, parameters, and reliability analysis for each method.

| | | Regression analysis | | | | |
|---|---|---|---|---|---|---|
| Model | Parameters | B | P | R | Durbin-Watson | ICC |
| TCI model | (Constant) | 43.180 | 0.000 | 0.204 | 1.762 | 0.148 |
| | Sex | 0.264 | 0.770 | | | |
| | CH | −0.493 | 0.296 | | | |
| | CPCH | −3.864 | 0.000 | | | |
| Novel model | (Constant) | 48.775 | 0.000 | 0.652 | 1.709 | 0.748 |
| | Sex | −0.262 | 0.710 | | | |
| | Pulp horn | −5.139 | 0.000 | | | |
| | Crown height | 2.640 | 0.000 | | | |
| | Pulp width | −6.476 | 0.000 | | | |
| | Crown width | 1.239 | 0.002 | | | |
| | RDT | 5.144 | 0.000 | | | |
| | Canal width | −14.315 | 0.000 | | | |

**Table 4.** Intra-observer and inter-observer agreement values of parameters.

| | CPCH | CH | A | B | C | D | RDT | E |
|---|---|---|---|---|---|---|---|---|
| Intra-observer agreement | 0.896 | 0.942 | 0.906 | 0.924 | 0.855 | 0.892 | 0.804 | 0.842 |
| Inter-observer agreement | 0.865 | 0.855 | 0.955 | 0.912 | 0.872 | 0.877 | 0.878 | 0875 |

accumulation of secondary dentin narrows the root canal as well as reducing the pulp chamber [30]. Therefore, the ratio of canal thickness to root thickness was also examined in the current study.

In the TCI method, pulp height is examined according to the cementoenamel junction line. Due to the position of the tooth in the dental arch, diffuse radiolucent areas, called burnout, may occur on the mesial and distal aspects of cervical regions of the teeth on panoramic radiography [31]. The burnout phenomenon and superimposition of structures can obscure the start and end points of the cementoenamel junction line. In addition, regardless of age, abfraction at the cervical region due to hard brushing or bruxism may result in loss of enamel and consequently inaccurate determination of the cementoenamel junction [32]. Failure to determine the cementoenamel junction on the mesial and distal cervical regions results in the baseline not being arranged correctly. This situation causes relative results in the measurements of pulp height.

The cementoenamel junction does not allow precise interpretation in cases where the pulp is very thin and appears at the apical aspect of the cementoenamel junction. In a previous study, it has been shown that the pulp chamber was at the level of the cementoenamel junction in 97% of mandibular molars [33]. In the novel method, to determine the crown height, a line defined as a 'furcation line' passing through the furcation point was used instead of the cementoenamel junction line. Unlike the cementoenamel junction, the furcation point is unquestionably clear on panoramic radiography. The location of furcation does not change due to radiographic and external factors. Thus, the furcation line is a suitable and more stable line for measurements.

In the new staging system, crown height was measured from the point where dentin was the highest, without including enamel. Pathological tooth wear, including attrition or erosion, can cause enamel loss as an age-independent process [34]. After the enamel development is complete, most of the ameloblasts, enamel-producing cells, degenerate, and except for the influence of mechanical and pathological factors, the thickness of the

enamel does not change throughout the life of the tooth [35]. In the novel method, enamel, which does not affect age estimation, was not included in the measurements. Crown height measurements were performed from the highest dentin point to the furcation line.

For the reliability of age staging systems, the standard deviation of recommended methods should be below ±10 years [36,37]. Based on the literature, there are various methods to detect chronological age in adults. Kvaal's method was one of the commonly used techniques for age estimation in adults. Previous studies using Kvaal's formula showed that the standard deviation range was from 5.6 to 14.4 years [11,38,39]. These studies analysed Kvaal's technique using 100–300 radiographs. A large sample size may provide better accuracy. The minimum number of study samples should be 120 for acceptable results for age staging research [40]. Another limitation of previous studies is using the cementoenamel junction as a reference line in Kvaal's model. The cementoenamel junction, as concluded before, can be a misleading reference point for dental age estimation methods. The current study has a large sample size and more reliable reference lines compared with previous studies. Another method for age estimation is the Cameriere model that examined the pulp/tooth ratio area. Previous studies reported that standard error estimation varies between ±1.2 and 12 years [6,41]. Standard errors of estimation of the novel model exceeded ±10 years (SD = 11.04) whereas the estimation error of the TCI model was ±14.25 years. However, standard errors of each subgroup for the novel model were found to be ±8.19, 6.01, 7.65, and 9.92 for Groups 1, 2, 3, and 4, respectively. According to the previous studies using the TCI model, the correlation coefficient range is −0.178 to 0.49 [5,24,42]. In this study, the correlation coefficient of the TCI and novel model was found to be 0.204 and 0.652, respectively. The novel method has a higher correlation than the TCI model in our study.

The current study reported that there was no significant difference between males and females. There was another study using TCI conducted by Tidke et al. [43] using panoramic and periapical radiography. Their study observed that using TCI in males has better applicable method than females in panoramic radiography [43]. In contrast to other studies, there was a statistical significance for sex [23,44]. The amelogenin gene that was a marker in sex determination produced enamelin structures [45]. There may be one possible explanation for different results for the sex that enamel was not included in our study. The amelogenin gene that was a marker in sex estimation produces enamel structures [45]. However, in the novel method, the crown height was measured without including enamel. This may be one possible explanation for the incongruence with previous studies. If the sex of an individual cannot be recognized, the new staging system can be useful due to not being affected by sex.

There are numerous dental age estimation methods based on radiological findings. Radiation-related concerns remain controversial. Panoramic and hand–wrist radiography were the mostly used methods in dental age estimation. Despite the radiographic techniques using a low radiation dose, experts should avoid radiography in accordance with the ALARA (as low as reasonably achievable) principles [46]. However, researchers reported that dental age estimation methods have better accuracy than other methods in estimating chronological age [47,48]. Forensic experts should prefer dental methods with low radiation doses and digital radiographic techniques. If previous radiography of a patient is available, forensic odontologists should use these radiographs and avoid taking new radiographs. In accordance with the current literature, non-ionizing imaging

techniques, such as magnetic resonance imaging (MRI) and ultrasound, are not applicable. Further research is needed to assess the maturation of hand and wrist using ultrasound and MRI.

In the current study, age indicators were evaluated with panoramic radiography. Evaluating panoramic radiography for age estimation is advantageous compared with periapical radiography because it provides access to all teeth [5]. Furthermore, when using periapical radiography, the long-cone paralleling technique should be applied to avoid inaccurate measurements due to distortion in the image. However, the film holders and long-cones required for the long-cone paralleling technique are not commonly used equipment. Tidke et al. [43] compared X-ray techniques in age estimation. They found there was no significant difference between panoramic and periapical radiography. Owing to periapical radiographs obtained by different techniques possibly causing misleading consequences, we preferred panoramic radiography instead of periapical radiography.

The current study examining the novel method on the Turkish subpopulation used a limited sample. Previous research indicated that dental formation with age can be different in different regions of the same country [49]. Various studies that evaluated the applicability of the Demirjian method in different Turkish subpopulations indicated that the discrepancy between chronological and dental age is range from −1.2 to 1.69 years [49,50]. Another study evaluated the maturation of third molars in Turkish children from the Southwest Eastern Anatolian region. The findings of this study revealed that development of third molars was earlier in children from the Southwest Eastern Anatolian region than for other populations [51]. Taken together with previous research, the results of our study should be considered to be reliable for the Southern Turkish population. Further studies should examine the applicability of the new staging system in different regions of the Turkish population and with different populations. The parameters and reference points examined in the current study can be used to create regression models in different methods and with different populations. In addition, the novel method should be examined using periapical radiographs obtained by the long-cone paralleling technique.

## Conclusion

(1) Our study showed that the results of the TCI model are not effective method to the Turkish population.
(2) The parameters of our novel model have better accuracy than TCI's. This study showed that parameters based on the furcation level as a reference line are more reliable than those base on the cementoenamel junction because of the burnout phenomenon and the superimposition of structures in panoramic radiography.
(3) Based on the new staging system, sex is not significant for age estimation. The reason for this might be not measuring enamel.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## References

1. Nemsi H, Salem N, Bouanene I, Jomaa B, Belhadj M, Mosrati MA, Amor B, Chadly A. Age assessment in canine and premolar by cervical axial sections of cone-beam computed tomography. Legal Med. 2017;28:31–36. doi:10.1016/j.legalmed.2017.07.004.
2. International Organization for Migration, UN Migration. World migration report 2020. 2020. Available from: https://www.un.org/sites/un2.un.org/files/wmr_2020.pdf .
3. Schmeling A, Grundmann C, Fuhrmann A, Kaatsch HJ, Knell B, Ramsthaler F, Rötzscher K. Criteria for age estimation in living individuals. Int J Leg Med. 2008;122(6):457–460. doi:10.1007/s00414-008-0254-2.
4. Black S, Aggrawal A, Payne-James J. Age estimation in the living. West Sussex: Wiley-Blackwell; 2010.
5. Jain S, Nagi R, Daga M, Shandilya A, Shukla A, Parakh A, Singh R. Tooth coronal index and pulp/tooth ratio in dental age estimation on digital panoramic radiographs—a comparative study. Forensic Sci Int. 2017;277:115–121. doi:10.1016/j.forsciint.2017.05.006.
6. Zaher JF, Fawzy IA, Habib SR, Magdy AM. Age estimation from pulp/tooth area ratio in maxillary incisors among Egyptians using dental radiographic images. J Forensic Leg Med. 2011;18:62–65. doi:10.1016/j.jflm.2010.12.004.
7. Cameriere R, Ferrante L, Belcastro MG, Bonfiglioli B, Rastelli E, Cingolani M. Age estimation by pulp/tooth ratio in canines by periapical X-rays. J Forensic Sci. 2007;52(1):166–170. doi:10.1111/j.1556-4029.2006.00336.x.
8. Cunha E, Baccino E, Martrille L, Ramsthaler F, Prieto J, Schuliar Y, Cattaneo C. The problem of aging human remains and living individuals: a review. Forensic Sci Int. 2009;193(1–3):1–13. doi:10.1016/j.forsciint.2009.09.008.
9. Kırzıoğlu Z, Ceyhan D. Accuracy of different dental age estimation methods on Turkish children. Forensic Sci Int. 2012;216(1–3):61–67. doi:10.1016/j.forsciint.2009.09.008.
10. Star H, Thevissen P, Jacobs R, Fieuws S, Solheim T, Willems G. Human dental age estimation by calculation of pulp–tooth volume ratios yielded on clinically acquired cone beam computed tomography images of monoradicular teeth. J Forensic Sci. 2011;56:77–82. doi:10.1111/j.1556-4029.2010.01633.x.
11. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int. 1995;74(3):175–185. doi:10.1016/0379-0738(95)01760-G.
12. Oi T, Saka H, Ide Y. Three-dimensional observation of pulp cavities in the maxillary first premolar tooth using micro-CT. Int Endod J. 2004;37(1):46–51. doi:10.1111/j.1365-2591.2004.00757.x.
13. Ubelaker DH, Parra RC. Application of three dental methods of adult age estimation from intact single rooted teeth to a Peruvian sample. J Forensic Sci. 2008;53(3):608–611. doi:10.1111/j.1556-4029.2008.00699.x.
14. Ekizoglu O, Er A, Bozdag M, Akcaoglu M, Can IO, Garcia-Donas J, Kranioti E. Sex estimation of the tibia in modern Turkish: a computed tomography study. Leg Med. 2016;23:89–94. doi:10.1016/j.legalmed.2016.10.004.
15. Brooks S, Suchey J. Skeletal age determination based on the os pubis: a comparison of the Acsa´diNemeske´ri and SucheyBrooks methods. Hum Evol. 1990;5:22738. doi:10.1007/BF02437238.
16. Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP. Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. Am J Phys Anthropol. 1985;68:1528. doi:10.1002/ajpa.1330680103.

17. Iscan MY, Loth SR, Wright RK. Metamorphosis at the sternal rib end: a new method to estimate age at death in White males. Am J Phys Anthropol. 1984;65:14756. doi:10.1002/ajpa.1330650206.
18. Christensen AM, Passalacqua NV, Bartelink EJ. Forensic anthropology: current practice and methodology. San Diego (CA): Elsevier; 2014.
19. Cameriere R, Ferrante L, Cingolani M. Precision and reliability of pulp/Tooth area ratio (RA) of second molar as indicator of adult age. J Forensic Sci. 2004;49:131923. doi:10.1520/JFS2004125.
20. Kvaal SI, Solheim T. A non-destructive dental method for age estimation. J Forensic Odontostomatol. 1994;12:611.
21. Drusini AG, Toso O, Ranzato C. The coronal pulp cavity index: a biomarker for age determination in human adults. Am J Phys Anthropol. 1997;103(3):353–363. 10.1002/(SICI)1096-8644(199707)103:3%3C353::AID-AJPA5%3E3.0.CO;2-R.
22. Karkhanis S, Mack P, Franklin D. Age estimation standards for a Western Australian population using the coronal pulp cavity index. Forensic Sci Int. 2013;231(1–3):412–e1. doi:10.1016/j.forsciint.2013.04.004.
23. Igbigbi PS, Nyirenda SK. Age estimation of Malawian adults from dental radiographs. West Afr J Med. 2005;24(4):329–333. doi:10.4314/wajm.v24i4.28227.
24. Talabani RM, Baban MT, Mahmood MA. Age estimation using lower permanent first molars on a panoramic radiograph: a digital image analysis. J Forensic Dent Sci. 2015;7(2):158–162. doi:10.4103/0975-1475.154597.
25. Godge P, Sharma S, Vibhakar P, Kulkarni S, Shroff J. Age estimation using orthopantomographs-a forensic study. Int J Oral Care Res. 2014;2:26–30.
26. Shreshta M. Comparative evaluation of two established age estimation techniques (two histological and radiological) by image analysis software using single tooth. J Forensic Res. 2014;5:2–6.
27. Akay G, Karatş MS, Karadağ Ö, Gungor K, Üçok Ö. An application for Olze's method and tooth coronal index for age estimation of a Turkish adult population. Aust J Forensic Sci. 2020;52(6):699–710. doi:10.1080/00450618.2019.1676466.
28. Boyacioglu Dogru H, Avcu N, Akkaya N, Yılancı HO, Goksuluk D. Applicability of Cameriere's and Drusini's age estimation methods to a sample of Turkish adults. Dentomaxillofac Radiol. 2017;46(7):20170026. doi:10.1259/dmfr.20170026.
29. Hargreaves, Kenneth M., Harold E. Goodis, and Franklin R. Tay, eds. *Seltzer and Bender's dental pulp*. Quintessence Pub., 2012.
30. Gu Y, Lu Q, Wang H, Ding Y, Wang P, Ni L. Root canal morphology of permanent three-rooted mandibular first molars—part I: pulp floor and root canal system. J Endod. 2010;36(6):990–994. doi:10.1016/j.joen.2010.02.030.
31. White SC, Pharoah MJ. Oral radiology: principles and interpretation. 7th ed. St. Louis: Mosby; 2013.
32. Palamara D, Palamara JEA, Tyas MJ, Messer HH. Strain patterns in cervical enamel of teeth subjected to occlusal loading. Dent Mater. 2000;16(6):412–419. doi:10.1016/S0109-5641(00)00036-1.
33. Deutsch AS, Musikant BL. Morphological measurements of anatomic landmarks in human maxillary and mandibular molar pulp chambers. J Endod. 2004;30(6):388–390. doi:10.1097/00004770-200406000-00003.
34. Eisenburger M, Addy M. Erosion and attrition of human enamel in vitro part I: interaction effects. J Dent. 2002;30(7–8):341–347. doi:10.1016/S0300-5712(02)00048-9.
35. Tsuchiya M, Sharma R, Tye CE, Sugiyama T, Bartlett JD. Transforming growth factor-β1 expression is up-regulated in maturation-stage enamel organ and may induce ameloblast apoptosis. Eur J Oral Sci. 2009;117(2):105–112. doi:10.1111/j.1600-0722.2009.00612.x.
36. Soomer H, Ranta H, Lincoln MJ, Penttila A, Leibur E. Reliability and validity of eight dental age estimation methods for adults. J Forensic Sci. 2003;48(1):1–4. doi:10.1520/JFS2002253.
37. Babshet M, Acharya AB, Naikmasur VG. Age estimation in Indians from pulp/tooth area ratio of mandibular canines. Forensic Sci Int. 2010;197(1–3):125. doi:10.1016/j.forsciint.2009.12.065.

38. Rajpal PS, Krishnamurthy V, Pagare SS, Sachdev GD. Age estimation using intraoral periapical radiographs. J Forensic Dent Sci. 2016;8(1):56. doi:10.4103/0975-1475.176955.
39. Kanchan-Talreja P, Acharya AB, Naikmasur VG. An assessment of the versatility of Kvaal's method of adult dental age estimation in Indians. Arch Oral Biol. 2012;57(3):277–284. doi:10.1016/j.archoralbio.2011.08.020.
40. Saxena S. Age estimation of Indian adults from orthopantomographs. Braz Oral Res. 2011;25 (3):225–229. doi:10.1590/S1806-83242011005000009.
41. Babshet M, Acharya AB, Naikmasur VG. Age estimation from pulp/tooth area ratio (PTR) in an Indian sample: a preliminary comparison of three mandibular teeth used alone and in combination. J Forensic Leg Med. 2011;18(8):350–354. doi:10.1016/j.jflm.2011.07.003.
42. Nagi R, Jain S, Agrawal P, Prasad S, Tiwari S, Naidu GS. Tooth coronal index: key for age estimation on digital panoramic radiographs. J Indian Acad Oral Med Radiol. 2018;30 (1):64–67. doi:10.4103/jiaomr.jiaomr_139_17.
43. Tidke P, Kulkarni S, Agrawal V, Saxena U, Pandharipande R. Tooth coronal index (TCI), antegonial angle, and antegonial depth measurement for age estimation using digital panoramic radiograph. J Indian Acad Oral Med Radiol. 2019;31(4):353–358. doi:10.4103/jiaomr.jiaomr_111_19.
44. Żądzińska E, Drusini AG, Carrara N. The comparison between two age estimation methods based on human teeth. Anth Rev. 2000;63:95–101.
45. Simmer JP, Hu JCC. Dental enamel formation and its impact on clinical dentistry. J Dent Educ. 2001;65(9):896–905. doi:10.1002/j.0022-0337.2001.65.9.tb03438.x.
46. Hendee WR, Edwards FM. ALARA and an integrated approach to radiation protection. Semin Nucl Med. 1986;16(2):142–150. doi:10.1016/S0001-2998(86)80027-7.
47. Schmidt S, Nitz I, Ribbecke S, Schulz R, Pfeiffer H, Schmeling A. Skeletal age determination of the hand: a comparison of methods. Int J Legal Med. 2013;127(3):691–698. doi:10.1007/s00414-013-0845-4.
48. Corradi F, Pinchi V, Barsanti I. Garatti S Probabilistic classification of age by third molar development: the use of soft evidence. J Forensic Sci. 2013;58(1):51–59. doi:10.1111/j.1556-4029.2012.02216.x.
49. Celik S, Zeren C, Celikel A, Yengil E, Altan A. Applicability of the Demirjian method for dental assessment of southern Turkish children. J Forensic Leg Med. 2014;25:1–5. doi:10.1016/j.jflm.2014.04.006.
50. Tunc ES, Koyuturk AE. Dental age assessment using Demirjian's method on northern Turkish children. Forensic Sci Int. 2008;175(1):23–26. doi:10.1016/j.forsciint.2007.04.228.
51. Orhan K, Ozer L, Orhan AI, Dogan S, Paksoy CS. Radiographic evaluation of third-molar development in relation to the chronological age of Turkish children in the southwest Eastern Anatolia region. Forensic Sci Int. 2013;232(1–3):238–e1. doi:10.1016/j.forsciint.2013.07.023.